EFFECTS OF FIELD CELL-REMOVAL TIME ON THE OVERWINTERING SURVIVAL OF THE ALFALFA LEAFCUTTING BEE, *MEGACHILE ROTUNDATA* (FABRICIUS)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Usual practice in propagation of the alfalfa leafcutting bee (Megachile rotundata (F.)) is to remove nesting cells from alfalfa (Medicago sativa L.) seed fields after pollination has been accomplished. It is generally assumed that the harvesting or collecting of the alfalfa leafcutting bee cells must occur in the late summer or fall, just prior to frost or immediately after frost, depending on climatic and management factors. Collected cells are held in cold storage at ca. 4 °C until they are incubated the following growing season. Alfalfa leafcutting bee cells are incubated in the spring at ca. 29 °C until bees begin to emerge about three weeks later. At this time cells are placed in the field to coincide with alfalfa bloom.

Oklahoma was once among the leading states in alfalfa seed production, however, today there are few Oklahoma farmers who produce seed crops. Those who do usually rely on native bee populations for pollination, and populations may be inadequate. Alfalfa leafcutting bees are now being utilized to a small extent, but no studies had been undertaken until 1979 to determine efficacy and adaptability

of this bee to Oklahoma seed growing areas.

A preliminary study in 1982 in which alfalfa leafcutting bee cells were brought from the field to cold storage on two dates showed a difference in the percentage of bees and parasites emerging during incubation the following spring. As a result of this initial study, it was decided to investigate the effect of removing cells from the field at additional sampling dates.

The basic concept investigated was when should cells be removed from fields to maximize percentage of adult emergence. However, several other factors related to removal times were studied. They were 1) parasitism, 2) predation, 3) disease, 4) leafcutting bee larval mortality due to other causes, 5) leafcutting bee sex-ratio, 6) effect of cell position in nest on sex, disease, parasites, etc., and 7) position in shelter on nest selection. All of these factors may have an influence on overwintering survival of the alfalfa leafcutting bee.

CHAPTER II

REVIEW OF LITERATURE

Origin and Spread

The alfalfa leafcutting bee, Megachile rotundata (Fabricius), apparently originated in southwestern Asia or southeastern Europe (Bohart 1962). It was accidentally introduced to the east coast of the United States in the 1930's (Mitchell 1937), and had spread throughout the country by the 1950's (Parker 1982). It was discovered to be an excellent pollinator of alfalfa (Medicago sativa L.) Stephen and Torchio (1961) reported it to be abundant in southern Idaho and Oregon about this time. By 1958 it also had spread to Nevada and Utah, and was found in all the alfalfa seed production areas in Washington by 1961 (Eves and Johansen 1974). The bee was later successfully introduced into western Canada in 1962 (Krunic 1972).

The pollinating potential of the leafcutting bee for alfalfa seed crops was first suggested by Bohart (1962) and Stephen and Torchio (1961), and it has been used extensively in the western United States, Canada, New Zealand, South America and Europe (Klostermeyer 1982). Hobbs (1973) stated that the alfalfa leafcutting bee is the only bee that can be relied on to pollinate flowering alfalfa seed fields in

Canada. Utilizing this bee, alfalfa seed can be produced economically in Canada wherever the bee can thrive and where growing and harvesting conditions are good for alfalfa.

The alfalfa leafcutting bee, M. rotundata, is solitary by nature. It is also gregarious. These bees are considered semi-domesticated because they nest close to each other and in many types of man-made structures. For this reason, they have been successfully propagated under various climatic conditions (Johansen et al. 1979). M. rotundata is unable to construct its own nesting holes. It nests in natural holes in wood, earthen banks, or those made by other insects also.

Alfalfa seed growers in the West and Pacific Northwest have been aware of the value of these bees since the late 1950s. The technology and management of the bee has evolved into a multimillion dollar industry in support of alfalfa seed production (Kish et al. 1981).

Life History

The size of the alfalfa leafcutting bee varies from 5 to 10 mm long and 2 to 4 mm wide (Johansen et al. 1979). Females are dark, and have short, white setae on various parts of their bodies. They have a pollen brush made up of long white bristles on the ventral side of their abdomens. Males have two light colored spots on the ventral side at the apex of the abdomen. They do not possess a pollen collecting brush that females do.

The female leafcutting bee builds from four to seven cells in a suitable nesting tunnel and then repeats the process in other tunnels. Usually all cells within a given tunnel contain live siblings (Vandenberg and Stephen 1982). The cells are thimble-shaped and made of leaf pieces that the female cuts and carries with her mandibles (Bitner 1976). Leaf pieces are pushed into and set against the sides of nesting tunnels. Each cell is provisioned with nectar and pollen. A single egg is laid on the outer surface of each pollen mass. After the egg hatches, the larva feeds on the pollen and nectar mass and develops through five growth stages to a mature larva.

In a laboratory rearing study conducted at 17 °C. and 55% relative humidity, Tirgari (1963) reported the following average number of days required for each growth stage of M. rotundata: first instar, 2; second through third instar, 1.8; fourth instar, 1.5; fifth instar larva, 2.6; and prepupa 3.7 days. A total of 11.6 days is required for larval development. Eves and Mayer (1980) reported that egg to mature larva requires 14-21 days. Until maturation into a prepupae, the larva has a blind gut, and therefore cannot defecate and contaminate its food and cell quarters (Hobbs 1973). The bee either overwinters as a prepupa, which is the diapausing stage, or emerges the same year. Pupation takes place after a week or more of incubation, depending on incubation temperature and previous conditioning at cold temperatures (Tirgari 1963). Tirgari

(1963) reported that pupae remained translucent for three or four days after which time pigmentation proceeded. Adult emergence occurred one to two days after the pupae turned completely black. For bees wintering under ambient conditions, spring emergence coincides with the early bloom of uncut alfalfa (Klostermeyer 1982). For prepupae held in cold storage, which is the usual management practice, pupation begins about a week after incubation at 30 °C Adult emergence begins in 18 days and is completed in 34 days (Hobbs 1973). Males emerge first, and three days later the females begin to emerge.

A 2:1 sex ratio of males to females is average, but a 1:1 ratio or even higher female ratio sometimes does occur (Johansen et al. 1979). Others have also reported variable sex ratios, but two to three males per female is the most common (Tirgari 1963; Osgood 1964; Stephen and Osgood, 1965a; Waters, 1969). Soon after emergence, mating occurs near to the nest. Unmated females produce only males. However, it is unusual for females not to mate. Gerber and Klostermeyer (1972) examined 800 females at a nesting site and found only three in which the spermatheca contained no sperm. A female usually lives 45-60 days and can potentially produce 25 to 40 cells in her life time (Bohart 1962). The average under normal field conditions is about 12 cells per female due to climatic, nesting, and other conditions (Eves and Mayer 1980).

Foraging Behavior

M. rotundata exhibits strong oligolecty to alfalfa in areas of the Pacific Northwest (Stephen and Torchio 1961). Stephen and Torchio (1961) indicate that it is, in fact, polylectic, and forages on pollen and nectar from a wide variety of floral sources. Bohart (1962) reported that besides being excellent pollinators of alfalfa, this leafcutting bee also pollinates and forages on sweet clover, Dutch clover, and a host of other plants. It trips (Figure 1) a high percentage of the flowers that it visits. In provisioning each cell the female bee trips enough flowers to produce 14 to 28 grams of alfalfa seed (Gerber and

Figure 1. Two Tripped Alfalfa Flowers
(Photo courtesy R. M. Ahring)

Klostermeyer 1972). Klostermeyer et al. (1973) found that females brought in 80% pollen and 20% nectar in their first load of provisions. The percentage of nectar was gradually increased in subsequent provisioning loads of the same cell. The final load was entirely nectar. They found that bees visited fewer flowers when collecting nectar alone, than when they were foraging for both nectar and pollen. Males do little pollinating, and spend their adult life-span either resting, mating or foraging for nectar (Hobbs 1973).

Nesting Behavior

The nest of M. rotundata consists of a series of cells that are arranged end to end in a tunnel. After the female constructs the cell walls with oblong leaf cuttings, she fills the cell about two-thirds full with pollen and nectar (Hobbs 1973). A Female's first cells, at the basal end of a nesting tunnel, contain females, and apical cells contain males. Males are perhaps better adapted to chewing its way out of its cocoon and through the leaf plug pieces due to a prominent molar surface on each mandible (Gerber and Klostermeyer 1972). The last cells constructed in a tunnel usually are the first to emerge. Rothschild (1979) found this to be true even when cells were removed from a tunnel and incubated separately. She also found that cell position, bee size, and emergence time are related and probably play some role in assuring proper emergence. Gerber and Klostermeyer (1972) found that both diameter and depth

of nesting tunnels had an effect on proportion of male to female cells.

Klostermeyer and Gerber (1969) monitored the nesting activity of M. rotundata with an event recorder (use of photocells to monitor nest entrance and exit). They found that a female bee requires an average of 2.45 hrs. to complete the construction of a single cell. The time was required for 15 leaf-collecting trips and 17 provisioning trips. A total of 7.7 minutes was spent in the cell between these trips. The various tasks while in the cell were construction and arrangement of leaf pieces, disgorging nectar in the nest, brushing off pollen, going into and backing out of the cell. Klostermeyer et al. (1973) found that there was a close association between the weight of provisions and the weight and sex of the resulting progeny. Bees further down the nesting tunnel chew their way through the debris left behind from earlier emerging bees. Often a female will use the nest from which she emerged for her first nesting site (Gerber and Klostermeyer 1972). Both males and females spend the nights in the nests.

Diapause

Initiation of diapause is temperature dependent in M. rotundata (Hsiao and Hsiao 1969; Stephen and Osgood 1965b). The progeny of a large percentage of M. rotundata overwinter as diapausing prepupae (Gerber and Aker 1969). Tirgari (1963) reported that diapausing larvae are C-shaped,

soft, smooth, cream colored and slightly widened anteriorly.

In the northwestern United States and southwest Canada, M. rotundata has at least a partial second generation (Eves and Mayer 1980). This means that instead of going into diapause, the insects pupate and develop to the adult stage the same season. Johansen and Eves (1973) reported that in the Pacific Northwest the leafcutting bee has two adult emergence periods each year. The second emergence is comprised of 10-20% nondiapausing bees. Parker and Tepedino (1982) reported that a substantial proportion of the second generation bees do not enter diapause but proceed to emerge when alfalfa bloom is sparse. They found that these bees either abandon their shelters in search of more abundant flowers or simply perish. Soon after the leafcutting bee was introduced into western Canada, the need became apparent for a univoltine strain of bee, that is, a strain whose first generation progeny develop only to the prepupal (diapause) stage. Second generation bees were emerging at a time when it was too late to reproduce or pollinate. Hobbs and Richards (1976) reported that up to 25% of the bees in a nesting area failed to diapause and emerged at a time when the days were too short and cool for any effective reproduction. According to Klostermeyer (1982), most larvae enter diapause, but some bees develop into second-generation bees in 23-28 days from the time the eggs were laid. In Canada, Krunic (1972) reported that over 50% of the cells that adult females completed by July 13

produced 2nd generation bees, whereas only 1.4% produced 2nd generation bees by the end of July. In Washington, 70 to 90% of bees nesting in June produced 2nd generation bees, 33 to 53% in the first half of July, 12% in the last half of July and none in August (Johansen et al. 1973). In all cases, latter produced cells contained a higher percentage of diapausing prepupae.

Diapause in M. rotundata is only partially facultative (Johansen and Eves 1973). Neither induction nor termination of diapause is exclusively controlled by environmental conditions. Beck (1963) reported that photoperiod and temperature are influential in determining the course of development in insects with a facultative diapause. Bitner (1976) found temperature and photoperiod not to be important in inducing diapause. Parker (1978) suggested that the adaptation of the female alfalfa leafcutting bee to local conditions contributed to percentages of prepupae entering diapause. Parker and Tepedino (1982) crossed two races of M. rotundata (from North America and Spain) differing in voltinism to study the maternal influence on diapause. Incidence of diapause was influenced by the origin of the bees. They found the diapause trait to be incompletely dominant and under polygenic control.

Disease, Parasites, Predators, and Nest Destroyers

When growers first began managing alfalfa leafcutting bees, propagation was relatively easy. Three to five-fold

population increases per year were not uncommon (Bitner 1978). There has been a gradual change in this situation. Bitner (1978) reported twenty different parasites and predators attacking the leafcutting bee. He reported a bee mortality factor of 50 to 75% due to these causes and disease, excessive heat, and pesticides. Bohart et al. (1976) stated that there were about 30 species of insect enemies associated with the alfalfa leafcutting bee. Johansen et al. (1979) reported that the Canadian chalcid, Pteromalus venustus Walker, can be serious pests during incubation of loose cells. Without control, up to 50% of bee larvae can be destroyed by these parasites.

The imported chalcid, Monodontomerus obscurus Westwood, is an "Old World" species. It has been introduced and has become one of the most common enemies of the leafcutting bee in the United States (Johansen et al. 1979). Females pierce the leaf cell with the ovipositor and deposits a number of eggs on the surface of the developing M. rotundata larva (Johansen and Eves 1966). Eggs hatch in about 36 hours. Larvae feed on the exterior of the bee larva and eventually consume it (Waters 1978). At room temperature, egg to pupa requires two weeks, and pupation requires an additional two weeks.

Melittobia chalybii Ashmead is a Nearctic species (Peck 1969), that is known to parasitize M. rotundata in California (Torchio 1963) and is also found in Canada. These three species, M. obscurus, P. venustus, and M. chalybii may

complete several generations per year without entering diapause (Hobbs and Krunic 1971). They can also overwinter as prepupae in cocoons of their hosts. Larvae of P. venustus and M. obscurus which were held in cold storage for over a year have survived and become adults, while M. chalybii has not (Hobbs and Krunic 1971). M. obscurus and P. venustus enter a facultative diapause, which can be terminated after a period of cold storage at 5°C (Krunic and Hinks 1972).

Briggs and Thorp (1982) ranked chalcids on the basis of their reproductive cycle: Melittobia sp. (30-60 eggs per host) and Monodontomerus sp. (6-18). In some areas a parasitic wasp, Sapyga pumila Cresson, has caused significant parasitism of leafcutting bee larvae. The sapygid female deposits one or more eggs through the cap of a leafcutting bee cell. Among predators and nest destroyers are the checkered flower beetle, Trichodes ornatus Say, carpet beetles and stored products pests, Trogoderma spp., which feed on pollen and old cells, and the flour beetle, Tribolium spp., which easily penetrates leafcutting bee cocoons. An unusual predator of Megachile is the blister beetle, Nemognatha spp. The first instar (triungulin) of the blister beetle attaches itself to a bee visiting a flower and is carried to the bee's nest where it feeds on the leafcutting bee's pollen and nectar (Johansen and Eves 1966).

Chalkbrood fungus disease is often the most serious of

mortality factors affecting leafcutting bees. Prior to 1973 a very low incidence of chalkbrood was reported. Recent losses have averaged 40 to 50% in Oregon, Idaho and Nevada (Johansen et al. 1979). It has also increased in leafcutting bee stocks in Washington and Canada. Chalkbrood is caused by a fungus (Ascosphaera spp.) (Stephen and Undurraga 1978). It is spread by means of spores. The broken bodies of infected larvae in their nesting holes and on shelter floors serve as sources of infection (Kish et al. 1979). These infectious spores cling to bodies of adults as they go about their nesting activities, and are present on nesting materials and around shelters. The spores must come in contact with the bee larva to be infective (Kish et al. 1979). An infected larva develops obvious symptoms as it swells and its color darkens. Infection to death requires at least 5 days to possibly weeks, and spore formation takes a minimum of 2 days from death to several weeks depending on external conditions. Briggs and Thorp (1982) reported that the incidence of chalkbrood increased as the season progressed. Stephen and Undurraga (1978) reported that the life history of the fungus is not known, and the manner of disease dispersal is not understood. Their opinion was that the disease is mainly disseminated by adults, which was latter substantiated by Vandenberg and Stephen (1982). Parker (1984) reported that the incidence of chalkbrood was significantly reduced when nesting units were treated with a fungicide (Captan) application. No detrimental effect was

found on nesting behavior as a result of treatment.

Unexplained egg and larval mortality often exacts a high toll on leafcutting bee populations. Briggs and Thorp (1982) found unexplained loss factor accounted for 42.1% of mortality. Thorp and Briggs (1972) found a correlation between bee mortality and saponin content in alfalfa leaves. Later field tests by Parker and Pederson (1975) did not confirm the laboratory results. Bohart et al. (1976) reported extremely high nesting material temperatures as a probable cause of this same mortality.

Management

The alfalfa leafcutting bee has many characteristics which encourage their manageability. It has long been known that alfalfa must be cross-pollinated to produce good quality seed in commercial quantities (Tysdal 1946). This has encouraged alfalfa seed growers to utilize this bee and understand bee management techniques. Aiding management practices is that M. rotundata covers only a short distance in foraging. Waters (1969) recommended 3700 to 8600 female bees for each hectare of seed production area.

Nesting Materials

In commercial alfalfa seed fields, females construct their nests in man-made materials. Among materials utilized to provide nesting tunnels are drilled boards, paper soda straws, and grooved plastic and wood laminates which can be

dismantled for cell removal (Stephen and Every 1970). Seventy-five to 80% of the growers in the Northwest use drilled boards with solid backs and have them redrilled and cleaned every two to three years (Bitner 1978). Bohart (1972) reported that drilled boards are the most common nest material in Idaho, Oregon, and Washington. Paper and plastic straws in western Nevada and grooved polystyrene laminates are most common in Nevada and Alberta, repectively. Bees will accept nesting holes with 0.3 to 0.6 cm diameters. Holes 0.5 to 0.55 cm in diameter and 6.4 to 8.9 cm deep seem to have greatest acceptance by the bees (Johansen et al. 1973). They suggested holes be deep enough to contain 6 or more cells, since tunnels shallower than 6 cm average less than 1 1/2 females per hole. The usual management practice is to place the nesting materials in shelters of various types and place them in and around fields during alfalfa flowering period (Johansen et al. 1973).

Shelter Design and Bee Acceptance

Shelters in the Pacific Northwest are designed to reduce heat build-up, while those in Canada are designed to contain heat (Pankiw and Siemens 1974). Bohart et al. (1976) stated that a good shelter is designed on the basis of bee habit and protection from negative environmental influences. He recommended that a shelter should incorporate a northeasterly exposure, protection from high angle sun rays, ventilation, and protection from wind.

Nest Removal and Storage

To protect the bees from nest destroyers in the winter, leafcutting bee cells can be stored in unheated buildings until the first alfalfa bloom (Hobbs 1968). Three weeks prior to when the bees are needed in the field for alfalfa pollination, they can be stimulated to emerge by incubating at 29 to 32 °C. More intensive management involves removing cells from nesting holes in the fall, placing them in cold storage, and incubating on trays prior to field placement (Stephen and Every, 1970). Advantages listed by Bohart (1972) in handling leafcutting bees in loose cells during the off-season include more efficient use of cold storage and incubating facilities, better nest destroyer control in the fall and chalcid control in the spring.

Timing Adult Emergence

It is common management practice to place diapausing larvae in cold storage over the winter. Post-diapause development does not occur below 19 °C (Stephen and Osgood 1965). Rank and Goerzen (1982) recommended that post-diapausing prepupae be incubated at 30 °C, and if necessary to retard development for optimum field placement, the temperature may be lowered to 15 to 20 °C for a time. To ensure better bee emergence with bloom synchrony, Waters (1969) found that when bloom was delayed, lowering the incubation temperature to 18 °C also effectively delayed emergence. Pankiw et al. (1980) found that the number of

days required for emergence varied inversely with the length of cold storage at 4 °C. They found the variance more pronounced in bees in more southern areas of Canada. Tirgari (1963) reported that the longer diapausing larvae were kept in cold storage, the earlier the onset of emergence during incubation. He also noticed a greater number of bees emerging from day to day. Johansen and Eves (1973) found that a cold period is not required to end diapause, but resulted in shortening the subsequent emergence time. Bohart et al. (1976) recommended that cells be removed from the field about 3 weeks after nesting is completed in the fall. Cells should then be placed in cold storage at 1.7-4.4 °C . Placing cells into cold storage at the beginning of the season will result in high mortalities due to killing of young larva and nondiapausing prepupae (Krunic 1972; Johansen and Eves 1973). In late spring they are incubated at 29-32 °C. Undurraga and Stephen (1980) reported that M. rotundata is well adapted to withstand temperatures slightly above and below its developmental threshold. After incubation at ca. 30 °C. for approximatedly 3 weeks, the bees are placed in field shelters as they begin emerging (Rank and Goerzen 1982). Krunic (1972) and Johansen and Eves (1973) reported that regardless of time of season, the greatest proportion of adult bees are produced from 1st generation cells of spring generation females at the beginning of nesting. It was suggested by Bohart et al. (1976) that more nesting materials should be added if and

when about 50% of the first set became filled with nests.

Control of Parasites

Trapping parasites from leafcutting bee incubation rooms can be accomplished simply by placing a pan of water beneath a light bulb (Hobbs 1968; Johansen and Eves 1966). Storage of alfalfa leafcutting bee cells at 1-4 °C also renders nest destroyers inactive. Hobbs (1968) recommended annual cleaning and screening of leafcutting bee nests to remove debris and discarding bee cells after bee emergence was complete to reduce debris-feeding insects.

CHAPTER III

MATERIALS AND METHODS

Preliminary Study

Alfalfa leafcutting bees (M. rotundata) were received from California, Idaho, Montana, Utah, Washington, and Alberta for a preliminary study at Woodward County, Oklahoma in 1982. In each of six fields, 7.6 liters of emerging bees from one of the out-of-state locations were placed in field shelters with appropriate nesting materials. One-half of the alfalfa leafcutting-bee nests were removed from each of six shelters at six alfalfa fields on August 25, and the other half on November 8. These nests containing cells were placed in cold storage. Individual cell samples were placed in a one-dram glass vial and incubated at ca. 29 C on May 25, 1983 to determine adult bee emergence rates and mortality factors.

Alfalfa Fields, 1983-84

In 1983-84, six alfalfa fields within a 20 km radius of Sharon, Oklahoma (Woodward County), were selected as replications for placement of alfalfa leafcutting bees. Weeks were treatments in the randomized complete block design. These fields ranged from 9 to 54 hectares. They

were cut for hay within a 10-day period of each other either late May or early June and the regrowth managed for seed production. Consistent field (alfalfa bloom) conditions were sought at initial bee release.

Prefield Release Cell Treatment

In March 1983, 60 liters of alfalfa leafcutting bee cells were received from Alberta, Canada. Upon arrival, the loose cells were placed in cold storage at ca. 4°C. On June 8, 30 liters of cells were spread uniformly at a depth of 5 to 8 cm in six, 46 x 71 cm wooden trays and placed in incubation chambers at ca. 29°C. On June 17, incubation of another 30 liters of cells were started. A light parasite emergence detected on June 20 was effectively controlled by a UV light-trap and spray applications of "Off", an insect repellent (N,N-diethyl-meta-toluamide),as recommended by Waters (1970) and Parker (personal communication). Fine mesh "Saran" screens were then used to cover the trays containing cells during incubation to prevent escape of emerging bees.

Shelters and Nesting Materials

Shelters were constructed of 0.95 and 1.3 cm thick 1.22 x 2.44 m sheets of plywood. Each shelter was ca. 1.22 x 2.44 m and was constructed in a rectangular fashion with a sloping roof covered with galvanized roofing material (Figure 2). The front was open for bee flight and nest access. Ventilation space in the back of the shelter was

provided. Each shelter was secured on all four corners to metal or wooden posts (making the peak of roof ca. 1.8 m from ground). One shelter was situated at the edge of each of six fields. Its front faced a northeasterly direction. Five cartons, denoted A,B,C,D,and E, were hung by hooks from a sheet of plywood attached to the back of each shelter (Figures 2 and 8) (carton F was attached to the NW inside wall two weeks after initial field release). Each carton measured 30 x 45 cm and was divided into 24 sections. In a randomized complete block design, fields were replications and cartons were treatments to test carton differences in bee emergence. Each section contained 62 paper nesting straws marked with colored clay orientation guides at the corners. Each straw was 9.5 cm long with a 6 mm diameter opening, and a wall thickness of 1 mm.

Field Release

Male leafcutting bees began emerging from cells in the first incubated trays on June 25, 1983. On June 28, two flats (10 liters) of emerging bees were released in each of three fields, designated A1,C1,and S1, which were in a more advanced flowering stage than the other three fields. The screen covers were removed (Figure 3), and the trays were suspended from the underside of the shelter roof, allowing continued bee emergence from the loose cells. These trays were left until emergence was complete. On July 7, the second incubation of emerging bees and loose cells were

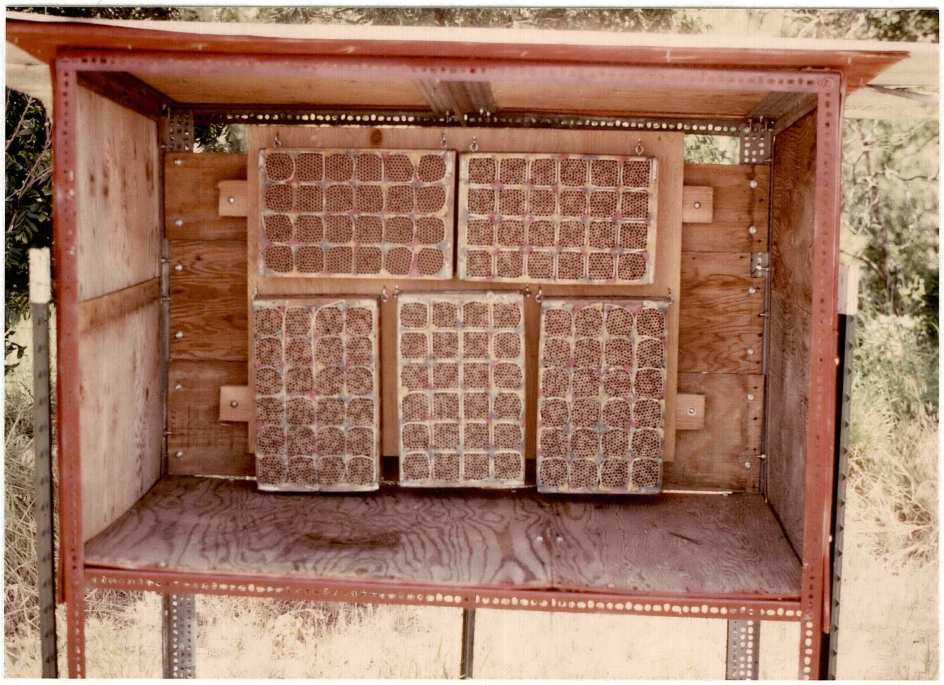

Figure 2. Alfalfa Leafcutting Bee Shelter and Carton Design

Figure 3. Release of Bees in Alfalfa Field

placed in the remaining three fields (A2,C2,and S2) in the same manner.

Sampling

Straws containing cells were collected at each location beginning at week 2 from the date of field release to study bee emergence rates, nonemergence factors, sex ratio, and prepupae determination. Eleven sampling periods were chosen: at week 2, 3, 4, 6, 8, 11, 17, 19, 26, 37, and 44. At each sampling period, 0, 1, or 2 straws (only those containing at least one cell) per section of each carton in each shelter of the six fields were removed. These straws were randomly chosen within a section using random numbers in an 8 x 8 pattern grid (Figure 4) (1st number indicating row and 2nd indicating column in section). Upon removal, if a straw was empty, it was replaced in its original position. If it contained at least one cell, its section number was recorded on the straw, and the straw was placed in a bag marked with date, field, and carton numbers. A dowel rod of equal size replaced the sampled straw in its original section position. During each sampling date, straws that had been filled (topped with cell caps) (Figure 5) were counted and recorded for each carton section in the six shelters before samples were removed.

Sample Treatment After Field Removal

The sampled straws with cells were kept at room

Field A1 Car E Date 7-19-83 Temp _____

1 87-21	2 55-67	3 33-28	4 47-71	5 77-67	6 88-63
7 54-58	8 38-46	9 63-32	10 76-55	11 63-17	12 86-56
13 45-32	14 47-33	15 87-21	16 36-84	17 15-21	18 36-87
19 26-44	20 83-52	21 45-16	22 45-57	23 48-53	24 14-77

Figure 4. 8 x 8 Random Number Pattern Sample Data Sheet

Figure 5. Dowel Rods and Nesting Straws

temperature for 3 days (or less, depending on time of year) and then placed in cold storage facilities at ca. 4 °C. Each bag of straws was given a number (1-341) representing the recorded information on the bag: field removal date, field, and carton from which the nesting straws were removed. Each bag contained up to 48 straws (2 per section). The straws in each bag were then further divided. One of the two straws from each section was placed in another bag, and an "X" (for X-ray) was recorded after the corresponding bag number. Of those sections which contained only 1 straw sample, one-half of the total number of these straws was placed in the "X" designated bag.

These straws were X-rayed with a Faxitron-804 X-ray unit having a range of 10-110 kVp to determine prepupal stage and cell frequency. From the end of January 1984 to the middle of May 1984, these nesting straws were removed from cold storage for less than one hour for X-radiography purposes. Kodak Industrex M2 X-ray film in ready pack form was used (Stephen and Undurraga 1976). Each bag of straws represented samples taken from one carton at a specific date and were placed on the film in order by section (Figure 6) and were exposed to 14.5 kVp for 3.25 min. The M2 X-ray film was then subjected to routine development procedures. Radiographs were examined and number of prepupal stage larvae as well as total cells per straw were recorded. All straws that were not x-rayed, and one-half of those that were, were designated to be opened for visual examination.

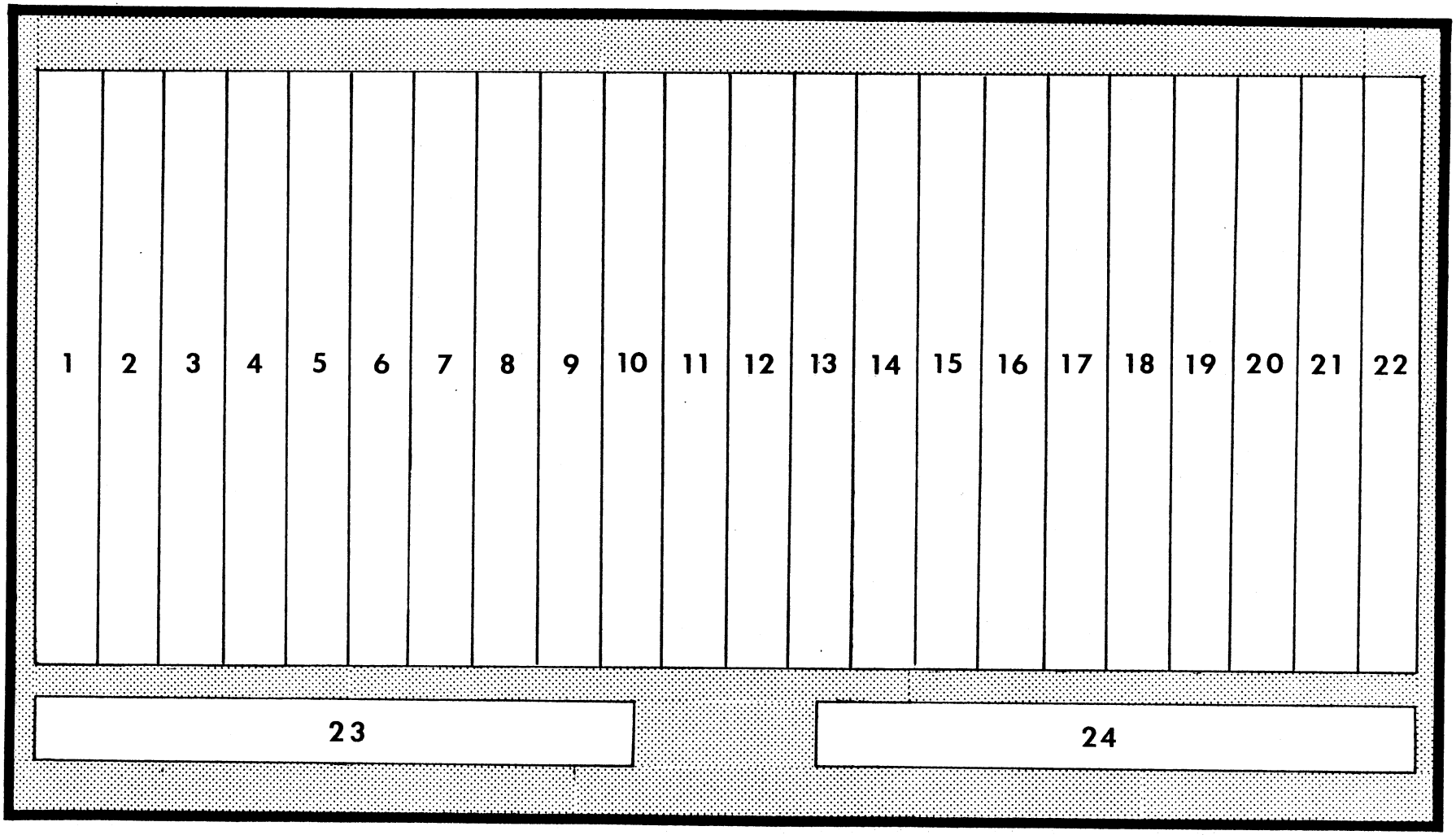

Figure 6. Diagram of Nesting Straws Placed on Film for X-Ray Analysis by Section

This was accomplished with a nesting straw holder-cutter device which cut laterally just through the straw side-wall on opposite sides, without cutting the intact cells (Figure 7). Each cell was removed from the opened straw and placed in an individual 1-dram vial and labeled to denote cell position within the straw, section, carton (Figure 8), field, and field removal date. Each vial was closed with a plastic cap which contained two holes made with an insect pin for air exchange. Due to the volume of cells incubated, and time and space requirements for processing, the straws were divided into six different groups. Four groups were randomly chosen for vial incubation processing. After placing the individual cell into a vial, it was returned to cold storage until all of its group cells were processed. These vials were placed on 42 x 32 cm trays. All trays from a group were placed in the incubation room at the same time. Temperatures fluctuated only slightly and averaged 27.8 °C over the total incubation period. Incubation of the first group began on June 6, 1984, the second on June 20, group three on July 5, and the fourth group on August 1. Total number of cells incubated in the four groups was 46,155. The cells were incubated for 45 days. Daily records were maintained on emergence of parasites, predators, and adult bees from individual cells. Emergence from each sampling week, cell position within a nesting straw, section, carton and field were recorded. Also, bee emergence and nesting cell numbers comparisons were made to determine any position

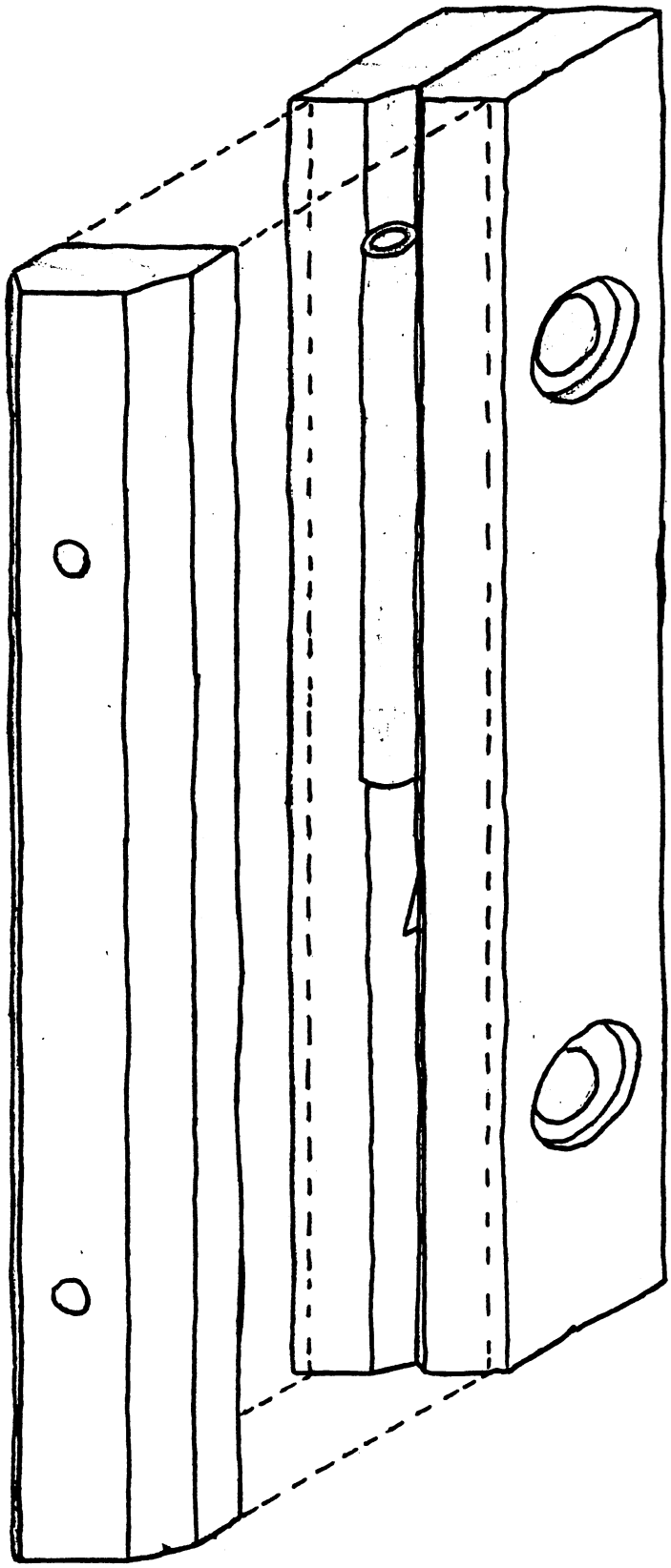

Figure 7. Matlock's Nesting Straw Holder-Cutter Device.

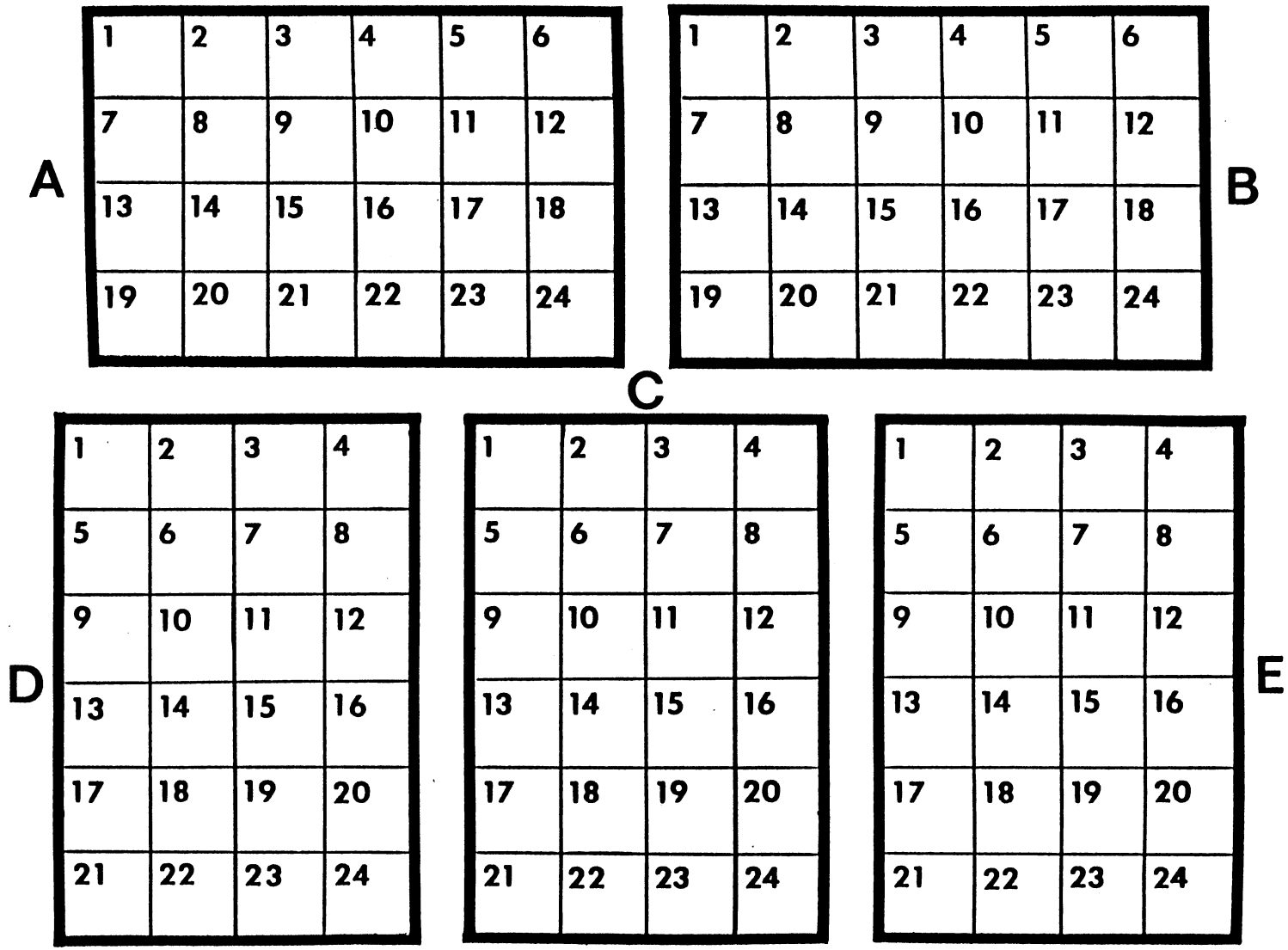

Figure 8. Nesting Carton Arrangement Within a Shelter.

effect within a shelter for outer and inner, as well as upper and lower, and left and right nesting areas (Figures 9-11). These same nesting positions were made for prepupa positions by X-ray analysis, as were filled nesting straw counts. In those cells from which nothing emerged after the 45-day period, a random sample of 240 cells for each of the eleven field removal dates was selected. These were examined visually to determine causes of mortality and nonemergence.

Scope of Analyses and Statistical Tests

Adult Bee Emergence

Numbers and percentages of adult bee emergence were determined for sampling weeks, fields, nesting cell position within an individual carton, and comparisons by cell position within outer-inner, upper-lower, and left-right shelter nesting areas (shelter nesting cell position). Statistical comparisons of nesting straw positions within a shelter (outer-inner, upper-lower, left-right) were made using a paired T-test. An ANOVA was used to determine effect of carton position (a,b,c,d, and e) in shelter on adult bee emergence. Fields and carton positions were replications and treatments, respectively. An ANOVA was also run on percent bee emergence as related to week, in which fields and weeks were replications and treatments, respectively. Duncan's New Multiple Range Test was then used to indicate if there were differences in percent bee emergence by week. No

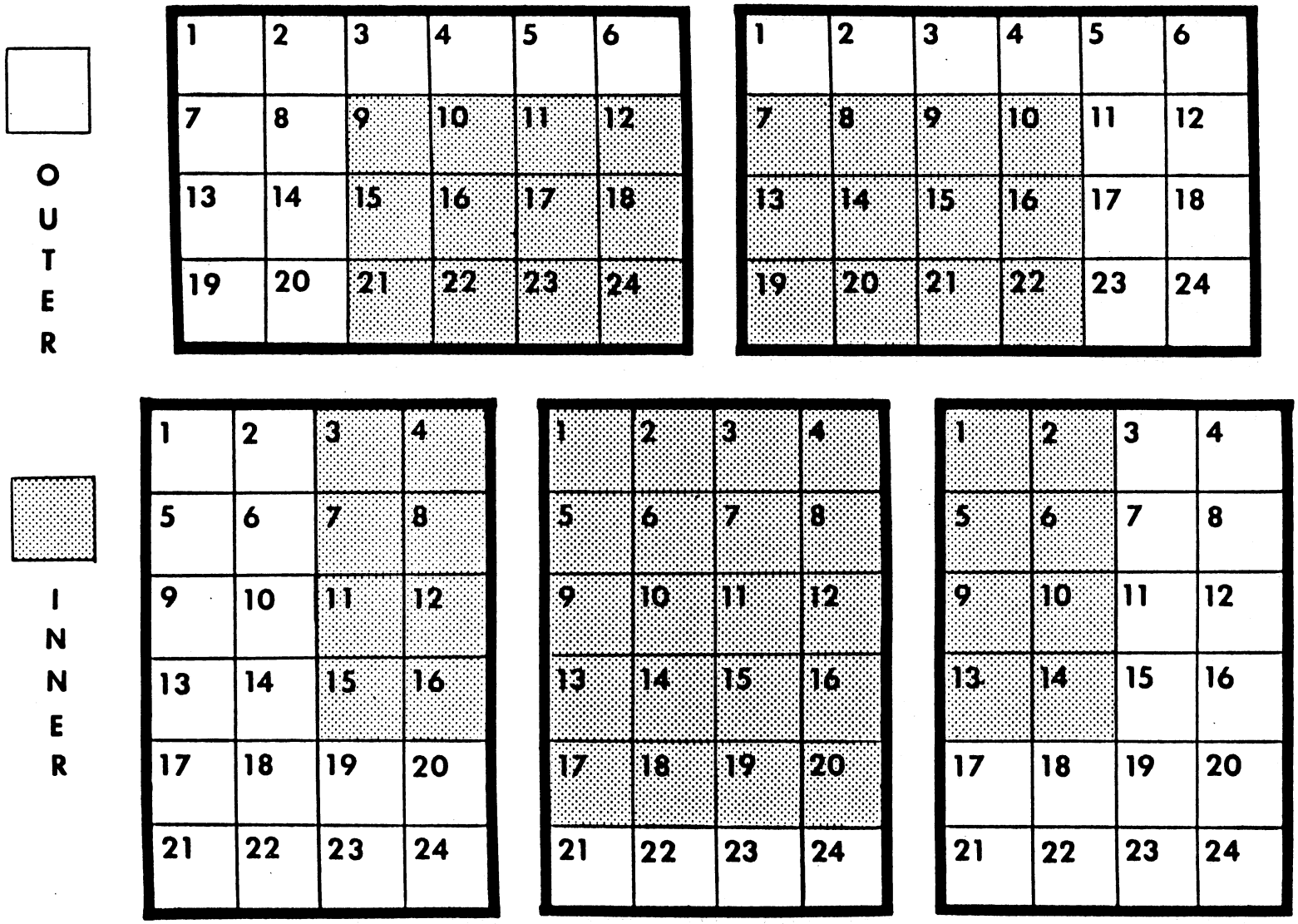

Figure 9. Outer and Inner Nesting Sections Within a Shelter

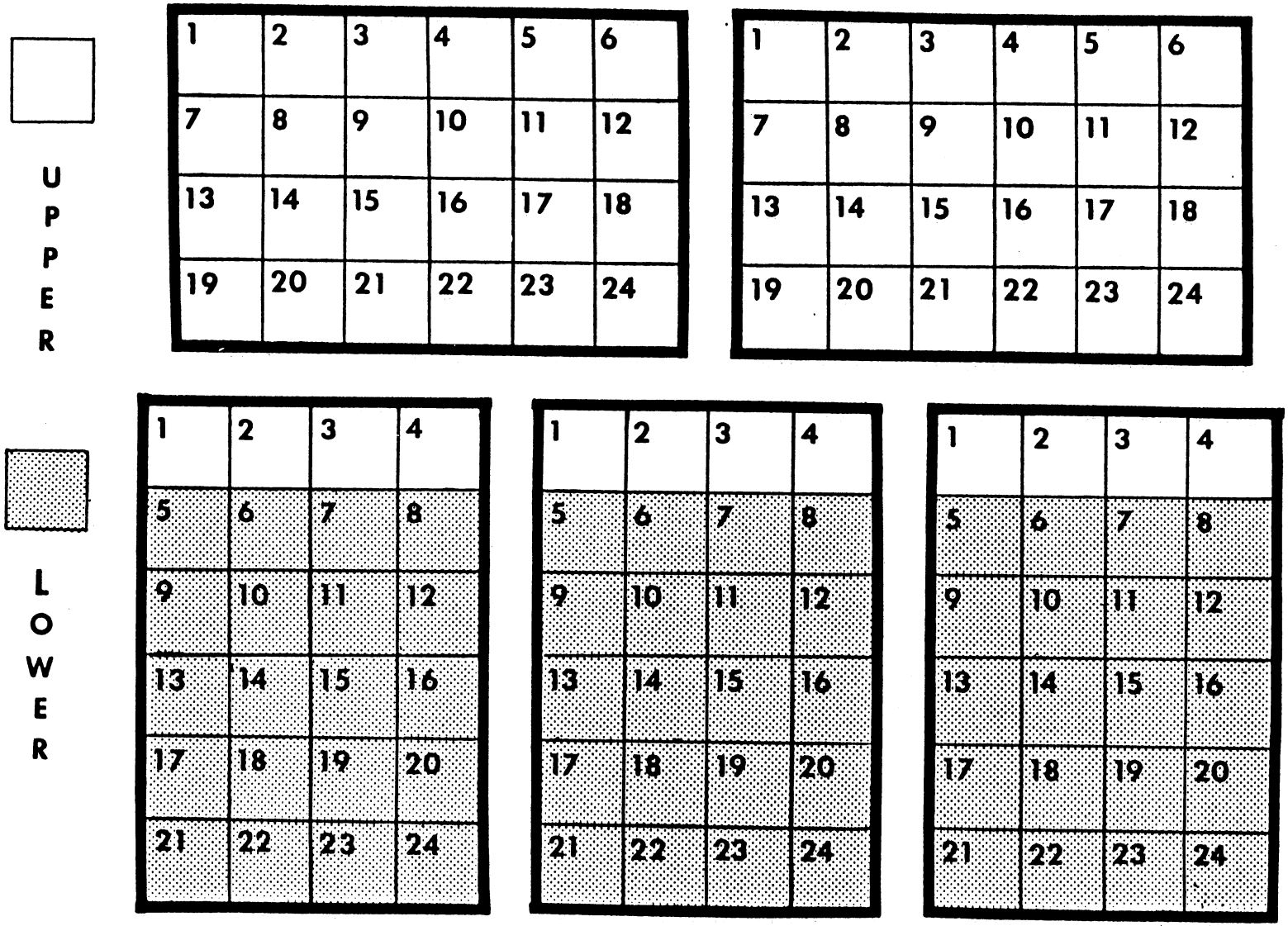

Figure 10. Upper and Lower Nesting Sections Within a Shelter

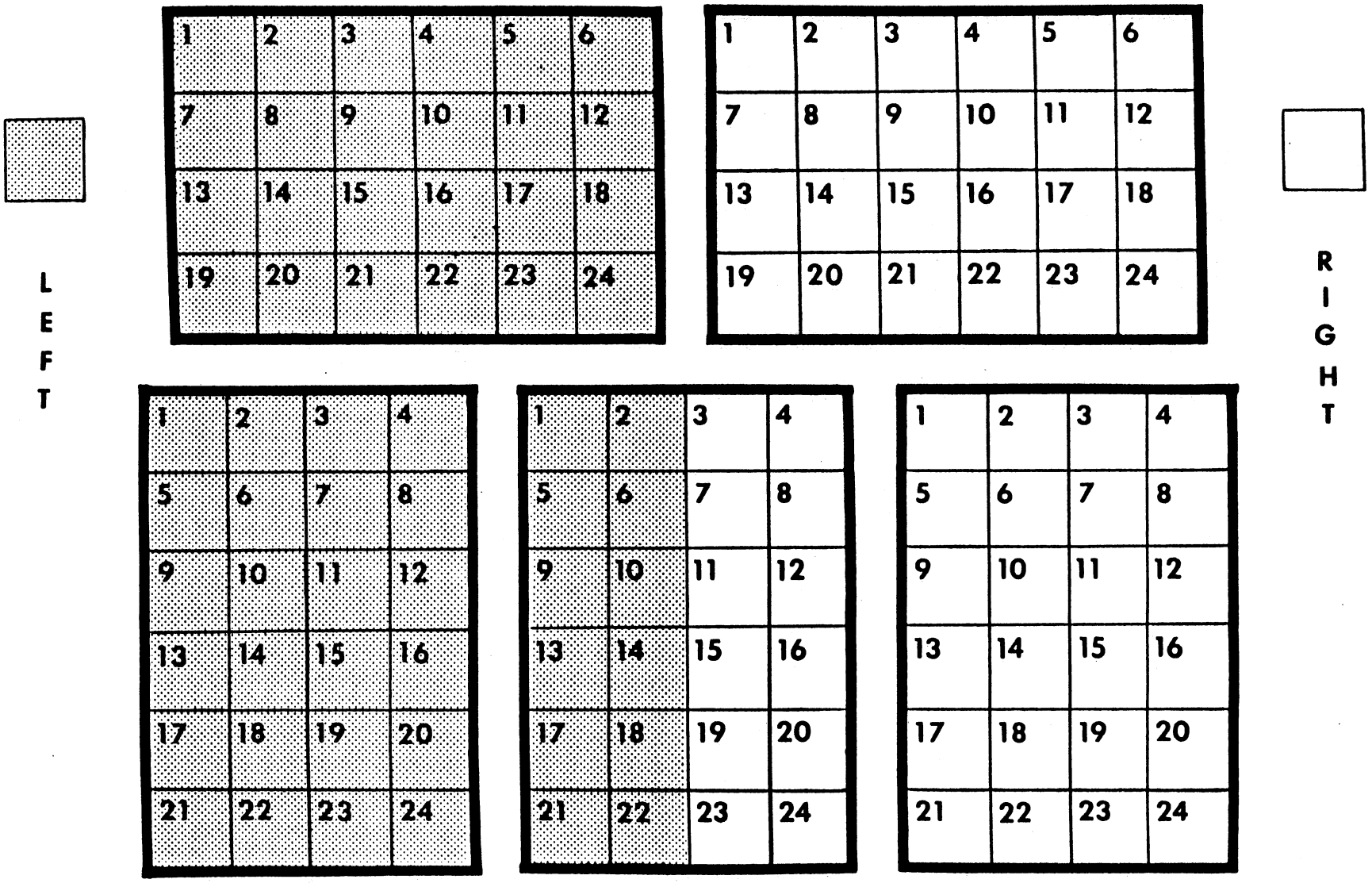

Figure 11. Left and Right Nesting Sections Within a Shelter

statistical tests were conducted to determine sampling week and field interactions on bee emergence.

Male and Female Bees

Numbers and percentages of adult bees were also separated by sex in the shelter nesting cell position comparisons, as well as by sampling weeks and fields. Mean incubation emergence times were recorded for male and female bees. No separate statistical tests were conducted on male and female bee emergence.

Parasites and Predators

Numbers and percentages of parasite and predator emergence were determined by sampling week, field, and nesting cell position within a shelter. Nesting cell positions within a straw samples were also recorded for emerging parasites and predators. No statistical tests were employed to parasite and predator emergence means.

Prepupae

Numbers and percentages of prepupae determined by X-ray analysis were also recorded by sampling week, field, carton, and nesting cell position within a shelter. Prepupae and bee emergence for sample weeks were compared only by line plots of their respective numbers.

To determine if there was any difference in bee emergence rates in those cells subjected to X-radiography, a

chi-square test on the arcsin mean transformation data per sampling week was run. No other statistical tests were performed on prepupae numbers.

Filled Nesting Straws

Numbers and percentages of filled nesting straws was determined by sampling week, field, carton, and nesting cell position within a shelter. A line plot of filled nesting straw numbers over the study period was used to estimate period of second-generation bee emergence, and compared to a line plot of numbers of bees emerging over the same period. No statistical tests were applied on filled nesting-straw counts.

Nonemergence Factors

In those cells of which nothing emerged after a 45-day incubation period, 240 cells from each sampling week were visually examined and determined to be dead in immature stage, infected by disease, damaged by predators or parasites, or empty. Percentages by week and field were recorded. No statistical tests were conducted.

CHAPTER IV

RESULTS

In the preliminary study of 1982, 47.5% more bees emerged from cells removed from field shelters on August 25 than those removed on November 8 (Table I). There was also a much lower rate of parasite and predator damage (bee larvae destroyed or consumed) on this earlier date. Alfalfa leafcutting bee cells received from Alberta, Canada produced more cells and progeny than the other five sources of bees (Maki and Moffett 1985).

Nesting Straw and Cell Sample Counts

In the 1983-84 study, a total of 46,155 alfalfa leafcutting bee cells in 14,341 nesting straws were removed from six shelters at 11 sampling dates over a 44-week period. The average number of cells per straw was 3.2. Numbers of straws which contained cells were slightly higher from the three fields in which the cells were placed a week earlier (A1,C1, and S1) than the last 3 fields (7976 to 6365) (Table II). Forty-eight straws from each nesting carton were sampled at each sampling week. Numbers of nesting straws removed at each sampling time was fairly consistent and averaged 1392. Low numbers were taken on

TABLE I

1200 ALFALFA LEAFCUTTING BEE CELLS FROM EACH OF TWO FIELD REMOVAL DATES INCUBATED TO DETERMINE RESULTANT BEE EMERGENCE AND NONEMERGENCE FACTORS, WOODWARD COUNTY, OKLAHOMA, 1982

	Removal Date	
	August 25	November 8
Total # of Leafcutting Bees Emerging	177	120
Male Leafcutting Bees	124	84
Female Leafcutting Bees	53	36
Cells with Parasites	4	61
Parasite and Predator Damaged Cells	25	96
Larvae Mortality	615	530
Disease	355	373
Empty Cells	24	20

TABLE II

NUMBER OF NESTING STRAWS SAMPLED CONTAINING ALFALFA LEAFCUTTING BEE CELLS, WOODWARD COUNTY, OKLAHOMA, 1983-84

Week	Field			Total	Week	Field			Total	Grand Total
	S1	A1	C1			S2	A2	C2		
2	240	240	237	717	2	211	240	165	616	1333
3	240	258	240	738	3	198	150	257	605	1343
4	288	257	232	777	4	212	219	169	600	1377
6	299	261	240	800	6	187	266	129	582	1382
8	293	254	237	784	8	192	270	153	615	1399
11	294	252	240	786	11	197	269	153	619	1405
17	279	260	240	779	17	231	288	164	683	1462
19	288	279	260	827	19	229	268	160	657	1484
26	288	259	240	787	26	229	265	155	649	1436
37	-	-	240	240	37	-	-	173	173	413
44	240	261	240	741	44	236	182	148	566	1307
Total	2749	2581	2646	7976	Total	2122	2417	1826	6365	14341

week 37 in which only 2 of the 6 fields were sampled due to inclement weather.

Bee Emergence

A total of 4703 alfalfa leafcutting bees emerged (Table III). From the samples collected two weeks after field release, just one bee emerged. At three weeks, only 1.1 percent of the cells contained prepupae that would subsequently develop into adults. After three weeks, the percentage of emergent bees increased steadily until it reached a peak of 18.5% (880 bees) at 17 weeks. The percentage then declined to 12.9% at 44 weeks. But due to a high variability in bee emergence among the fields, there was no significant difference at the 0.05 level of probability in percent bee emergence at weeks 8,11, 17, 19 26, and 44 (Duncan's New Multiple Range Test) (Table IV). There also appeared to be extensive interaction among fields and weeks. For example, in field A1, week 17 had the highest number of bees emerging, which declined through week 44. Field A2 had three similar peak bee emergences at weeks 11, 17, and 26. Fields C1, S1, and S2 had only one major peak of bee emergence, but that was at week 11, 19, and 8, respectively (Table V). Similar interactions appear between cartons and weeks, where highest percentages of bee emergence occur inconsistently at various sampling weeks in different cartons.

The overall adult overwintering survival was 10.2%.

TABLE III

NUMBERS AND PERCENTAGES OF ADULT (MALE AND FEMALE) ALFALFA LEAFCUTTING BEES EMERGING AFTER INCUBATION OF CELLS PREVIOUSLY REMOVED FROM SIX ALFALFA FIELDS AT VARIOUS WEEK INTERVALS, WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Cells	Bees	Percent Bees	Females	Percent Females	Males	Percent Males
2	4233	1	0.0	1	0.0	0	0.0
3	5040	56	1.1	38	0.8	18	0.4
4	5412	125	2.3	83	1.5	42	0.8
6	4341	364	8.4	182	4.2	182	4.2
8	4282	495	11.6	244	5.7	251	5.9
11	4608	733	15.9	294	6.4	439	9.6
17	4765	880	18.5	368	7.7	512	10.7
19	5005	844	16.9	413	8.3	431	8.6
26	3549	574	16.2	250	7.0	324	9.1
37	1647	210	12.8	106	6.4	104	6.3
44	3273	421	12.9	210	6.4	211	6.4
Total	46155	4703	10.2	2189	4.7	2514	5.4

TABLE IV

PERCENTAGE OF ADULT ALFALFA LEAFCUTTING BEES PER CELLS AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Field						Average Percent*
	A1	A2	C1	C2	S1	S2	
2	0.00	0.00	0.00	0.00	0.08	0.00	0.01 d
3	1.76	1.68	1.62	0.00	0.98	0.00	1.01 d
4	0.11	8.30	1.19	1.99	0.00	2.02	2.27 cd
6	1.25	21.60	7.06	3.19	0.36	11.06	7.42 bc
8	5.52	16.10	19.66	8.84	8.23	8.54	11.15 ab
11	8.89	26.44	21.09	7.62	9.48	7.12	13.44 ab
17	14.66	32.72	16.48	8.80	26.46	5.39	17.42 a
19	11.06	28.94	14.26	15.04	22.10	5.21	16.10 a
26	6.97	30.68	14.19	6.28	12.88	3.91	12.49 ab
44	7.84	25.74	11.58	12.80	14.16	3.86	12.66 ab
Average Percent	5.81	19.22	10.71	6.46	9.47	4.71	

*Week percentages followed by the same letter are not significantly different at the 0.05 level of probability (Duncan's New Multiple Test).

TABLE V

NUMBER OF ADULT ALFALFA LEAFCUTTING BEES EMERGING AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Field						Total
	A1	A2	C1	C2	S1	S2	
2	0	0	0	0	1	0	1
3	16	14	12	0	14	0	56
4	1	92	12	8	0	12	125
6	7	229	84	15	3	26	364
8	32	147	141	39	88	48	495
11	109	285	246	31	40	22	733
17	160	301	96	55	231	37	880
19	141	156	99	60	366	22	844
26	38	347	89	27	59	14	574
37	-	-	191	19	-	-	210
44	41	122	111	21	112	14	421
Total	545	1693	1081	275	914	195	4703

Early sampling dates when there was not sufficient time for development tended to lower the average percentage of overwintering bees. There was a five-fold difference in the number of cells removed and resulting bee emergence among the six field locations (replications). The low was 195 bees from 4729 cells and a high of 1693 bees from 8301 cells (4.1% to 20.4%) (Table VI). Cartons B and E contained the largest number of emerging bees (1087 and 1007, respectively), although in percentage emergence of adult bees, C and E was slightly greater (Table VII). Carton B had 61.5% more cells than carton C. An ANOVA on a Randomized Complete Block Design of percent bee emergence with fields as replications, and cartons (A,B,C,D, and E) as treatments, resulted in the F-value being not significant (no significant difference among cartons tested)(Table VIII). Carton F, which was placed in the shelters after the two-week sample was taken, consistently contained less cells and bees, and also a lower percentage of bees/cells than the other cartons (Table VII).

Cell Position Within Nesting Straws

The emergence ratio of females to males was 1:1.15 (2189 to 2514) over the 44-week sampling period. The first, or basal cells in a straw tend to be females, and from subsequent cells increasingly more males emerge (Figure 12). Adults emerging from the basal cell were 89.2% female, while adults emerging from the 9th cell position were 97.9% male.

TABLE VI

NUMBERS AND PERCENTAGES OF ADULT (MALE AND FEMALE) ALFALFA LEAFCUTTING BEES EMERGING PER FIELD AFTER INCUBATION OF CELLS PREVIOUSLY REMOVED FROM SIX ALFALFA FIELDS AT VARIOUS WEEK INTERVALS, WOODWARD COUNTY, OKLAHOMA, 1983-84

Location	Cells	Bees	Percent Bees	Females	Percent Females	Males	Percent Males
A1	8593	545	6.3	243	2.8	302	3.5
A2	8301	1693	20.4	729	8.8	964	11.6
C1	9877	1081	10.9	489	5.0	592	6.0
C2	4443	275	6.2	151	3.4	124	2.8
S1	10212	914	9.0	455	4.5	459	4.5
S2	4729	195	4.1	122	2.6	73	1.5
Total	46155	4703	10.2	2189	4.7	2514	5.4

TABLE VII

NUMBERS AND PERCENTAGES OF ADULT (MALE AND FEMALE) ALFALFA LEFUCTTING BEES EMERGING PER CARTON AFTER INCUBATION OF CELLS PREVIOUSLY REMOVED FROM SIX ALFALFA FIELDS AT VARIOUS WEEK INTERVALS, WOODWARD COUNTY, OKLAHOMA, 1983-84

Carton	Cells	Bees	Percent Bees	Females	Percent Females	Males	Percent Males
A	8665	817	9.4	430	5.0	387	4.5
B	11068	1087	9.8	533	4.8	554	5.0
C	6853	748	11.0	317	4.6	431	6.3
D	8926	918	10.3	418	4.7	500	5.6
E	8437	1007	11.9	445	5.3	562	6.7
F	2206	126	5.7	46	2.1	80	3.6
Total	46155	4703	10.2	2189	4.7	2514	5.4

TABLE VIII

PERCENTAGE OF ADULT ALFALFA LEAFCUTTING BEES PER CELLS FROM SIX NESTING CARTONS WITHIN A SHELTER AT SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Field	Carton						Average Percent
	A	B	C	D	E	F	
A1	7.23	4.75	3.13	6.98	10.54	2.70	6.34
A2	19.34	14.72	24.39	21.59	24.00	25.99	20.39
C1	11.93	10.72	11.60	5.28	13.84	–	10.94
C2	3.76	7.89	6.96	7.18	2.19	–	6.19
S1	9.73	15.90	7.97	10.80	5.40	2.08	8.95
S2	4.73	2.25	5.77	4.28	4.45	–	4.12
Average Percent	9.43	9.82	10.91	10.28	11.93	5.71	10.19

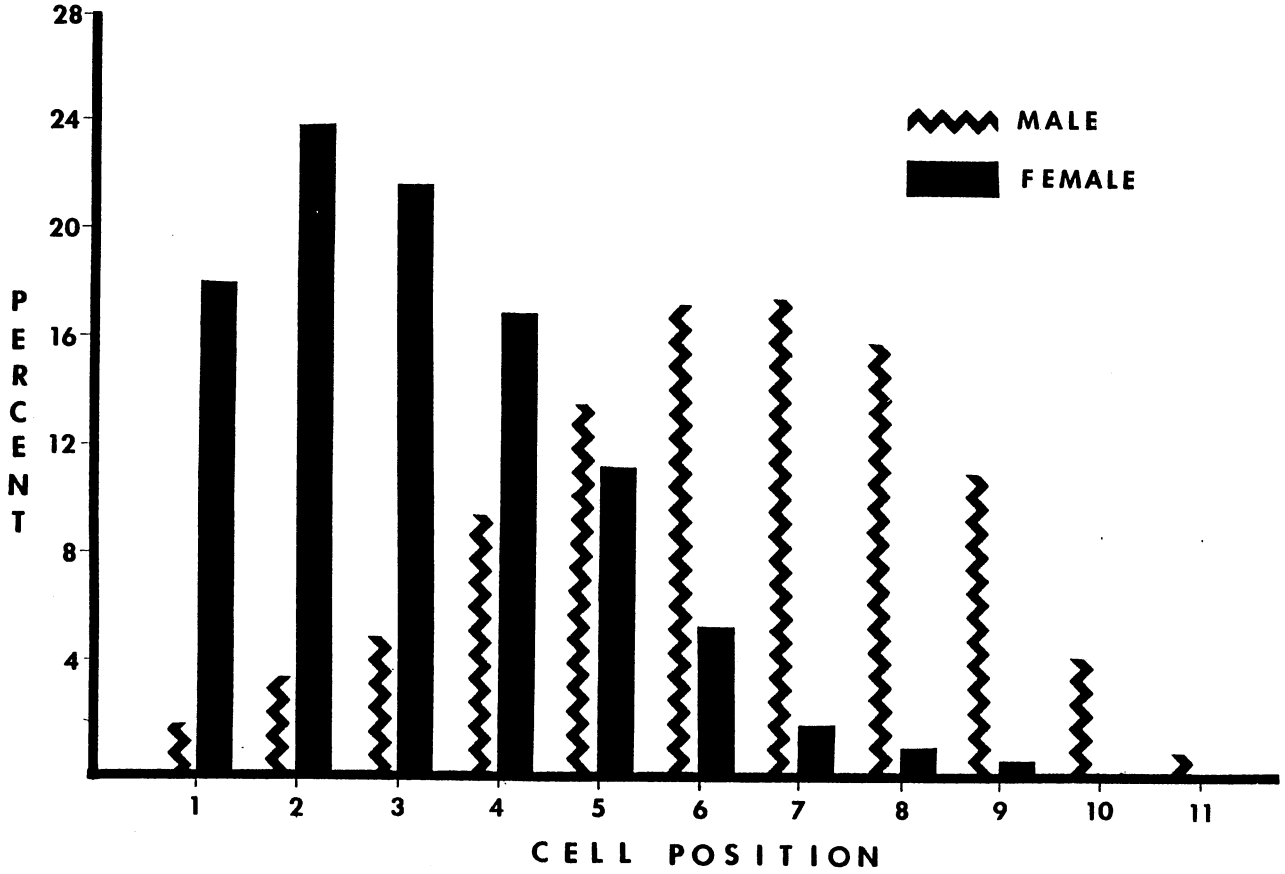

Figure 12. Nesting Straw Cell Positions of Emerging Male and Female Bees

The percentage of males increased in each subsequent cell to the 7th cell position (Table IX). Only 19.7% of the males were from cell positions 1-4, compared to 80.6% in positions 6-11.

Nesting Straw Position Within Shelter

Comparisons were made in bee emergence from cells taken from various portions of the cartons in the nesting shelters. Each of the nesting areas in the comparisons were equally divided in available nesting space. There were 2326 bees emerging from 21,846 cells in the outer portion of the nesting areas, and 2251 bees emerging from 22094 cells in the inner nesting areas (10.6% and 10.2% respectively) (Table X and Figure 9). There were 1.1% more cells in the inner, but 3.3% more bees emerging from the outer nesting areas. The peak number of bees emerging occurred at week 19 and the highest number of cells was at week 11 in the outer nesting areas. The highest percentage of adult emergence from the outer nesting areas was at week 17 (18.6%). The highest number and percent of bees and cells occurred at week 17 in the inner nesting areas (18.0%) (Table X). In the upper nesting positions (Figure 10), there were 2413 bees emerging from 23,960 cells sampled (10.1%). In the lower nesting positions, there were 2164 bees out of 19,980 cells sampled, or 10.8% (Table XI). There were 19.9% more cells in the upper nesting areas, which was the only shelter nesting position comparison which differed significantly at

TABLE IX

NUMBER OF EMERGENT MALE AND FEMALE ALFALFA LEAFCUTTING BEES, M. ROTUNDATA, AND PARASITES AND PREDATORS ACCORDING TO CELL POSITION WITHIN STRAWS AFTER FIELD REMOVAL, COLD STORAGE, AND INCUBATION OF CELLS

	Cell										
	1	2	3	4	5	6	7	8	9	10	11
Male	45	86	125	236	340	430	433	395	281	118	8
Female	370	520	495	368	248	113	41	14	6	1	0
Total	415	606	620	604	588	543	474	409	287	119	8
Parasites*	57	8	2	2	0	0	0	0	1	0	0
Predators	35	20	21	10	14	7	11	11	4	3	0
Total	92	28	23	12	14	7	11	11	5	3	0

*Indicates number of cells out of which parasites emerged.

TABLE X

ALFALFA LEAFCUTTING BEE CELLS AND EMERGING BEES FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM OUTER AND INNER NESTING POSITIONS FROM SIX SHELTERS

	Outer			Inner		
Week	Number of Cells	Number of Bees	Percent Bees	Number of Cells	Number of Bees	Percent Bees
2	2138	0	0.0	2095	1	0.0
3	2102	39	1.9	2558	17	0.7
4	2577	77	3.0	2515	48	1.9
6	2184	208	9.5	2089	156	7.5
8	1873	239	12.8	2028	231	11.4
11	2268	386	17.0	2083	343	16.5
17	2048	381	18.6	2533	457	18.0
19	2418	383	15.8	2283	446	19.5
26	1679	303	18.0	1549	231	14.9
37	836	107	12.8	811	103	12.7
44	1723	203	11.8	1550	218	14.1
Total	21846	2326	10.6	22094	2251	10.2

TABLE XI

ALFALFA LEAFCUTTING BEE CELLS AND EMERGING BEES FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM UPPER AND LOWER NESTING POSITIONS FROM SIX SHELTERS

	Upper			Lower		
Week	Number of Cells	Number of Bees	Percent Bees	Number of Cells	Number of Bees	Percent Bees
2	2478	1	0.0	1755	0	0.0
3	2767	30	1.1	1893	26	1.4
4	2534	37	1.5	2558	88	3.4
6	1839	142	7.7	2434	222	9.1
8	1937	215	11.1	1964	255	13.0
11	1969	311	15.8	2382	418	17.5
17	3016	596	19.8	1565	242	15.5
19	2484	462	18.6	2217	367	16.6
26	1850	268	14.5	1378	266	19.3
33	904	134	14.8	743	76	10.2
44	2182	217	9.9	1091	204	18.7
Total	23960	2413	10.1	19980	2164	10.8

the 5% level (paired T-test) (Table XII). Only 11.5% more bees were found in the upper area, which was not significantly different from the lower area at the 5% level. The peak number of bees and cells occurred at week 17 (19.8%) in the upper nesting areas, and at week 11 in the lower (17.5%) (Table XI).

In the left nesting positions (SE half of the shelter) (Figure 11), there were 2068 bees emerging from 20,014 cells sampled (10.3%). In the right nesting positions (NW half of the shelter) there were 2509 bees out of 23,926 cells sampled, or 10.5% (Table XIII). There were 19.5% more cells in the right nesting areas, and 21.3% more bees. The peak number of bees occurred at week 17 and cells at week 19 in the left nesting areas. The highest percent adult emergence was at week 17 (22.7). The highest number of bees in the right nesting areas was at week 19 and highest number of cells at week 17. The highest percentage of adult emergence occurred at week 19 (20.6) (Table XIII).

Female and Male Bee Emergence

Female bees in the outer nesting areas emerged from 5.1% of the cells. Inner nesting areas were 4.7% females (Appendix B, Table XXXV). Males in the outer and inner areas were 5.6 and 5.5 percent (Appendix C, Table XLIV). Females in the upper nesting areas emerged from 4.9%, compared to lower nesting of 4.8 percent (Appendix B, Table XXXVII). Males were 5.1 and 6.0 in the upper and lower

TABLE XII

UPPER VERSUS LOWER SHELTER NESTING POSITIONS OF CELLS SAMPLED FROM SIX ALFALFA FIELDS AT VARIOUS WEEKS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER							LOWER							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Upper	A1	A2	C1	C2	S1	S2	Lower	Total
2	375	246	624	121	686	426	2478	596	0	386	0	627	146	1755	4233
3	392	621	148	386	737	483	2767	431	175	594	85	482	126	1893	4660
4	354	423	420	402	431	504	2534	487	685	588	0	709	89	2558	5092
6	75	419	651	285	375	34	1839	417	641	538	185	452	201	2434	4273
8	294	367	352	283	393	248	1937	205	454	365	158	468	314	1964	3901
11	638	450	592	184	27	78	1969	588	628	574	223	138	231	2382	4351
17	385	626	570	380	635	420	3016	625	191	0	245	238	266	1565	4581
19	620	338	318	219	777	212	2484	582	201	376	180	648	230	2217	4701
26	284	423	323	283	290	247	1850	204	612	304	147	0	111	1378	3228
37			666	238			904			530	213			743	1647
44	523	243	617	164	397	238	2182	0	231	341	0	394	125	1091	3273
Total	3940	4156	5281	2945	4748	2890	23960*	4135	3818	4596	1436	4156	1839	19980*	43940

*Upper significantly different from lower at 0.05 level of probability (Paired T-test).

TABLE XIII

ALFALFA LEAFCUTTING BEE CELLS AND EMERGING BEES FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM LEFT AND RIGHT NESTING POSITIONS FROM SIX SHELTERS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	Left			Right		
Week	Number of Cells	Number of Bees	Percent Bees	Number of Cells	Number of Bees	Percent Bees
2	2169	0	0.0	2064	1	0.0
3	1936	33	1.7	2724	23	0.8
4	2212	53	2.4	2880	72	2.5
6	2120	232	10.9	2153	132	6.1
8	2078	234	11.3	1823	236	12.9
11	2096	339	16.2	2255	390	17.3
17	1826	414	22.7	2755	424	15.4
19	2033	280	13.8	2668	549	20.6
26	1634	236	14.4	1594	298	18.7
37	834	113	13.5	813	97	11.9
44	1076	134	12.5	2197	287	13.1
Total	20014	2068	10.3	23926	2509	10.5

areas (Appendix C, Table XLVI). Females in the left nesting areas emerged from 4.8%, compared to right nesting of 4.9 percent (Appendix B, Table XXXIX). Males were 5.5 and 5.6% in the left and right areas (Appendix C, Table XLVIII). Days of incubation required for emergence of both males and females generally declined with later field cell removal dates (Appendix B, Table XLI and Appendix C, Table L). Males began emerging sooner than females, with the highest emergence of males occurring at day 24, and females at day 27 after incubation (Figure 13).

Parasite Emergence

Only 71 (0.15%) of the cell samples incubated contained parasites and averaged 22.5 parasites per cell (Table XIV). These were primarily from field A2. Mainly the basal cells were parasitized. Most of the parasites were Pteromalus spp. Cells from the first five sampling weeks contained only 5.6% of the parasites. The last six contained 94.4%. The highest weeks were 19 and 26. Outer and inner nesting area comparisons for total cell numbers were 0.17 and 0.13%, respectively, for cells with parasites (Appendix D, Table LII). For upper and lower, 0.17 and 0.13 (Appendix D, Table LIII), and for left and right, 0.13 and 0.17%, respectively (Appendix D, Table LIV). Parasite emergence from cells removed at all sampling weeks began the sixth day after incubation, with the largest emergence occurring at day 12 (Figure 14). The basal cell contained 80.3% of the

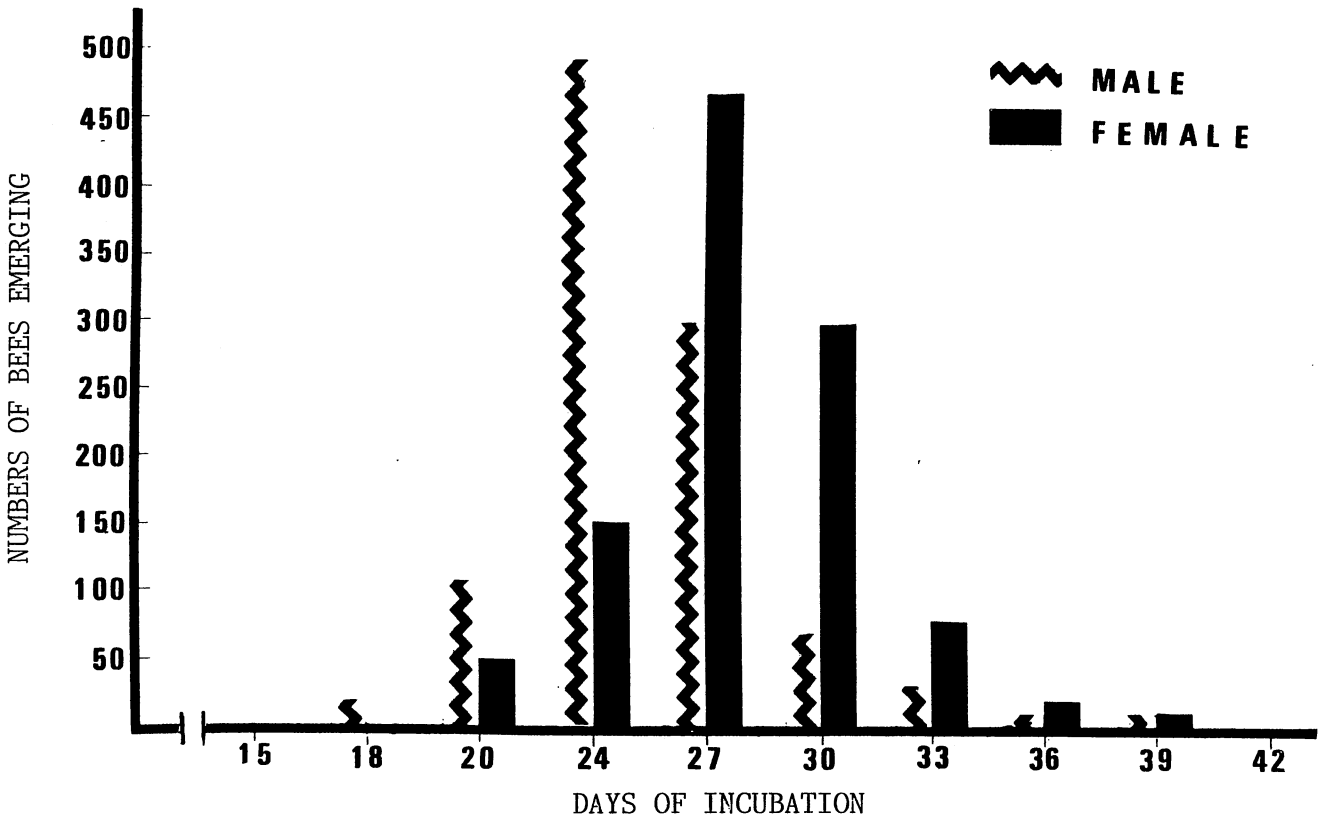

Figure 13. Emergence Time for Alfalfa Leafcutting Bees from Overwintered Cells at 27.8° C

TABLE XIV

ALFALFA LEAFCUTTING BEE CELLS WITH PARASITES EMERGING* AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Field					
	A1	A2	C1	C2	S1	S2
2	0	0	0	0	0	0
3	1	0	0	0	0	0
4	0	0	0	0	0	0
6	0	2	0	0	0	0
8	0	1	0	0	0	0
11	0	8	0	0	0	0
17	2	16	4	0	0	1
19	4	5	0	0	0	0
26	0	19	0	0	0	0
37	—	—	3	0	—	—
44	0	2	3	0	0	0
Total	7	53	10	0	0	1

*Average number of parasites emerging per cell = 22.5

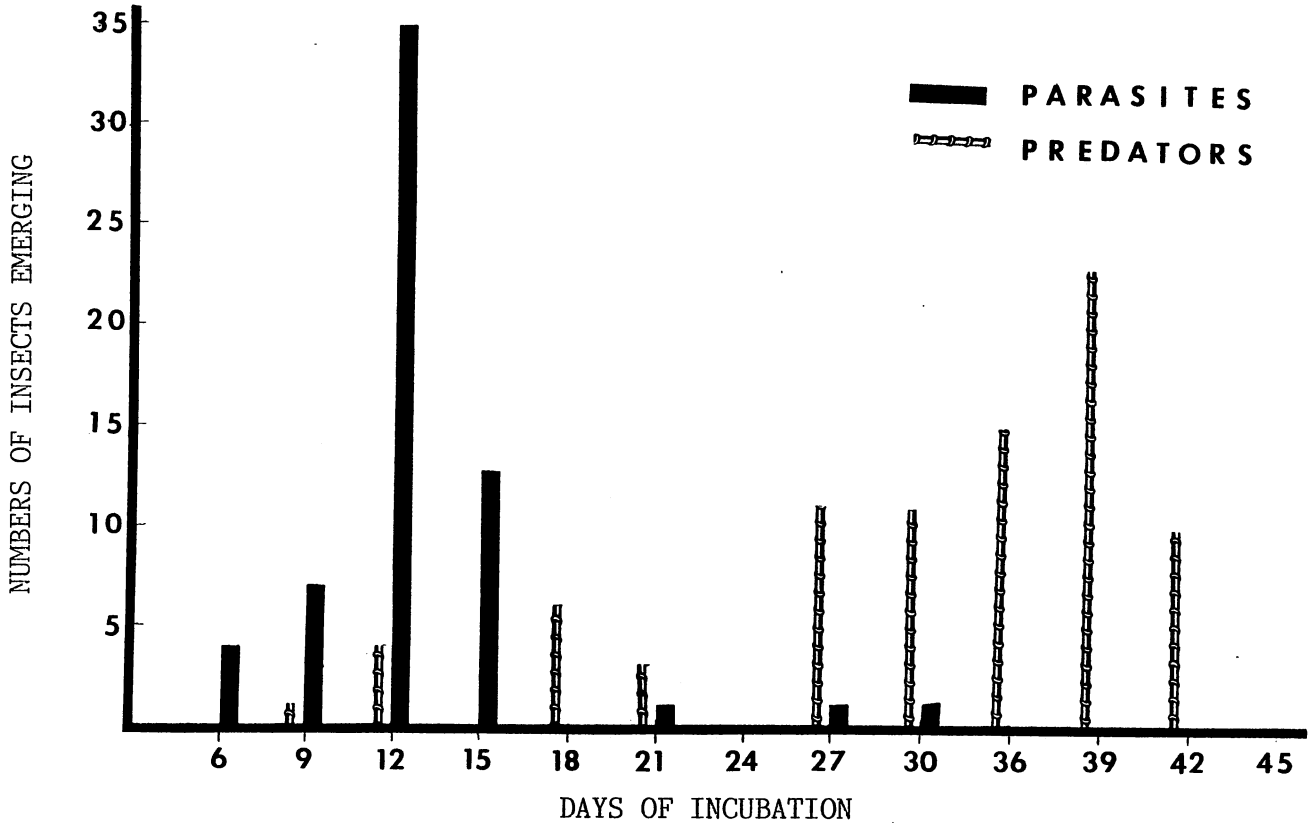

Figure 14. Emergence Time for Parasites and Predators from Overwintered Cells at 27.8° C

parasites found.

Predator Emergence

Only 135 (0.29%) predators emerged from 46,155 cells sampled (Table XV). The major predators were Plodia spp, and Nemognatha spp. Cells from the first five sampling weeks contained 34.8% of the predators. The last six contained 65.2%. The first sampling week, the middle , and the last sampling week contained approximately the same numbers of predators. Outer and inner nesting area predator comparisons with cell totals were 0.27 and 0.31%, respectively (Appendix E, Table LVI). For upper and lower, 0.30 and 0.28 (Appendix E, Table LVII), and for left and right, 0.25 and 0.32 percent, respectively (Appendix E, Table LVIII). Predator emergence from cells removed at all sampling weeks began at the ninth day after incubation, with the largest emergence occurring at day 39 (Figure 14).

Other Bees

Only 17 bees other than M. rotundata emerged from cells sampled throughout the study period. These were mainly Eumegachile pugnata Say. Very few native bees were observed nesting or near the leafcutting bee shelters.

Nonemergence Factors

Live emergence (males, females, parasites, predators, and other bees) accounted for 10.7% of the cells sampled. A

TABLE XV

PREDATORS EMERGING AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Field					
	A1	A2	C1	C2	S1	S2
2	1	0	7	0	9	0
3	0	1	0	0	1	0
4	0	4	6	0	3	0
6	0	0	1	3	5	0
8	0	0	2	0	3	1
11	4	3	6	0	2	0
17	1	4	0	8	4	2
19	4	8	3	0	3	2
26	2	3	6	1	2	0
37	—	—	0	3	—	—
44	6	6	1	0	3	1
Total	18	29	32	15	35	6

subsample of 240 individual cells per each field removal date was visually examined to determine nonemergence factors. Chalkbrood and other fungal diseases caused 32.7% mortality in the samples examined (Table XVI). Weeks 2, 3, 19, and 44 contained an average of 47.7% disease. The lowest incidence of disease was at weeks 6 and 8 (14.6%). Larval mortality accounted for 24.4% of the nonemergent cells. The percentage tended to decrease over the 44-week sampling period, beginning at 40.4% at week two and declining to 7.5% at week 44. Predator and parasite damage (cells in which damage, but no predator or parasites were found) accounted for 12.6% of non emergence factors. The lowest percentage of damage occurred at weeks two,three, and four (3.8%). Subsequent sampling dates accounted for 16.0% damage. Apparently empty cells accounted for 30.4% of the non-emergence factors. This was lowest at the first three sampling dates (6.9%) and increased to an average of 39.2% during the last 8 sampling dates (Table XVI).

Filled Nesting Straw Counts

At each sampling week, the number of filled nesting straws were counted at each field (Table XVII). The average week over the 44-week sampling period in the six fields was 2027. The number of filled nesting straws peaked to 4924 at week 4 (third sampling week) and steadily declined after second generation field emergence to 675 at week 44. Cartons A and B had the largest average number of filled

TABLE XVI

FACTORS AFFECTING PERCENTAGES OF NONEMERGENCE FROM A SUB-SAMPLE OF 240 INCUBATED ALFALFA LEAFCUTTING BEE CELLS PER WEEK REMOVAL DATE

Week	Disease	Empty Cell	Immature Stage Mortality	Predator or Parasite Damage
2	45.0	10.4	40.4	4.2
3	59.2	3.3	36.2	1.3
4	30.4	7.1	56.7	5.8
6	14.6	34.2	31.7	19.6
8	14.6	42.1	23.7	19.6
11	24.2	40.4	15.9	19.6
17	29.6	35.8	20.1	14.6
19	41.3	34.6	14.6	9.6
26	25.4	42.5	18.3	13.8
37	29.6	46.3	2.9	21.3
44	45.4	37.5	7.5	9.6
Avg. Total Percent	32.7	30.4	24.4	12.6

TABLE XVII

FILLED NESTING STRAWS AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Week	FIELD						Average
	A1	A2	C1	C2	S1	S2	
2	5181	3936	4003	1032	6016	2736	3817
3	6758	6474	4376	974	7702	3049	4889
4	6489	6845	4247	965	8034	2964	4924
6	1863	4310	1626	107	3218	429	1926
8	1084	3917	845	102	3567	294	1635
11	1024	2454	743	103	2767	275	1228
17	716	2982	760	80	2598	252	1231
19	687	2401	448	75	1887	207	951
26	728	2243	516	66	1867	203	937
37	–	–	449	68	–	–	86
44	590	1431	266	44	1522	194	675
Average	2284	3363	1662	329	3562	964	2027

straws (2793 and 2704) and carton D the lowest with 1974 (excluding carton F) (Table XVIII). The outer and inner average was 994 and 928, respectively (Appendix F, Table LIX). The upper and lower average was 1096 and 826, Appendix F, Table LX), and the left and right average was 964 and 958 filled nesting straws respectively (Appendix F, Table LXI). In all cases, the filled nesting straw counts were drastically reduced after the third sampling week (Figure 15).

X-Radiography Analysis

A total of 50,127 cells were subjected to X-radiography. Of these, 15,538 were included in the emergence analysis. Adult bees emerged from 9.76% of the X-rayed cells, and 10.41% of the cells not subjected to X-ray. The results of the chi-square test on the arcsin transformation data showed a significant difference (at the 0.04 OSL) in adult emergence (Table XIX).

Of the 50,127 cells X-rayed, 10,006 contained prepupae (20.0%). The first two sampling weeks yielded the highest number of prepupae (1307 and 1271) and largest percentage (30.0 and 26.2). These numbers tended to decline over the study period to 18.2% at week 44 (Tables XX and XXI). The highest number of prepupae was found in Carton A from the six shelters (2359, or 22.9%), and the lowest (excluding F) was Carton D with 8916 prepupae or 18.5% (Appendix G, Tables LXII and LXIII).

TABLE XVIII

FILLED NESTING STRAWS AT VARIOUS WEEKS FROM SIX CARTONS WITHIN A SHELTER AT SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Week	CARTON						Average
	A	B	C	D	E	F	
2	5600	5204	4058	4036	4006	0	3817
3	6180	6315	5355	5259	5404	820	4889
4	5993	6135	5177	5179	5268	1792	4924
6	2223	2078	1852	1813	1904	1683	1926
8	2241	2101	1639	1519	1629	680	1635
11	1847	1661	1034	1072	1235	517	1228
17	1959	1861	1025	956	1153	434	1231
19	1600	1538	704	696	718	449	951
26	1618	1513	686	660	732	414	937
37	155	162	46	52	102	0	86
44	1306	1172	456	475	468	170	675
Average	2793	2704	2003	1974	2056	633	2027

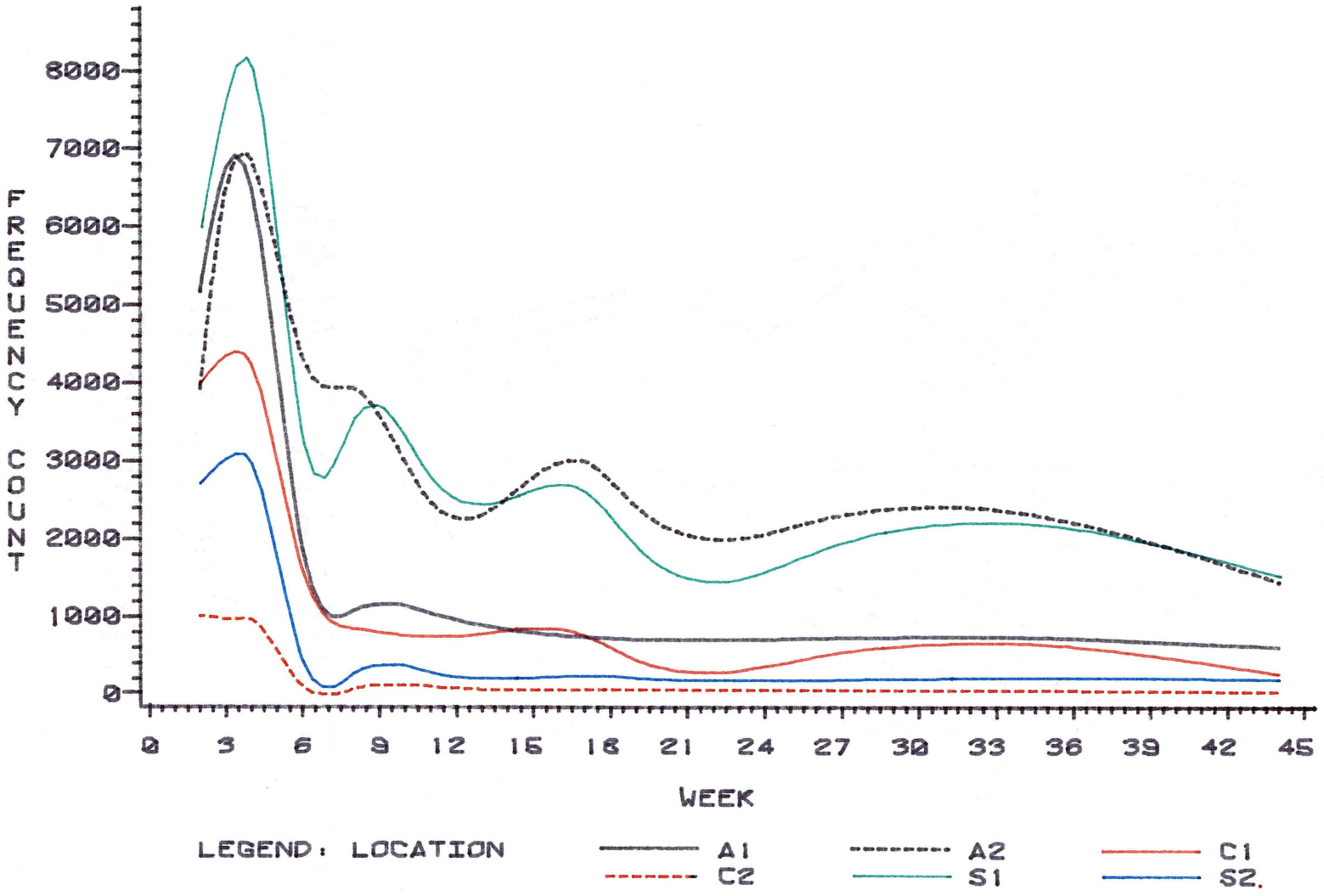

Figure 15. Straws Filled and Capped by Alfalfa Leafcutting Bees Over a 44-Week Period After Initial Field Release

TABLE XIX

EFFECT OF X-RAY ANALYSIS ON PERCENTAGE OF BEES EMERGING FROM OVERWINTERED CELLS

Week	Not Subjected to X-Ray			Subjected to X-Ray		
	Bees	Cells	Percent	Bees	Cells	Percent
2	1	2831	0.04	0	1402	0.00
3	39	3281	1.19	17	1759	0.97
4	97	3674	2.64	28	1738	1.61
6	227	2863	7.93	137	1478	9.27
8	338	2885	11.72	157	1397	11.24
11	449	2927	15.34	284	1681	16.89
17	616	3163	19.48	264	1602	16.48
19	560	3277	17.09	284	1728	16.44
26	425	2358	18.02	149	1191	12.51
37	159	1089	14.60	51	558	9.14
44	275	2269	12.12	146	1004	14.54
Total	3186	30617	10.41	1517	15538	9.76

TABLE XX

ALFALFA LEAFCUTTING BEE PREPUPAE DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS

Week	Field						Total
	A1	A2	C1	C2	S1	S2	
2	201	127	223	157	401	198	1307
3	150	427	387	55	139	113	1271
4	91	399	226	36	48	44	844
6	69	387	202	8	47	74	787
8	99	398	169	42	249	36	993
11	129	413	192	47	251	24	1056
17	81	371	84	40	302	46	924
19	45	331	150	38	313	27	904
26	96	347	141	28	245	52	909
37	–	–	136	20	–	–	156
44	106	304	133	54	229	29	855
Total	1067	3504	2043	525	2224	643	10006

TABLE XXI

ALFALFA LEAFCUTTING BEE CELLS DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS

Week	Field						Total
	A1	A2	C1	C2	S1	S2	
2	905	774	843	375	925	539	4361
3	864	961	872	372	1175	610	4854
4	1006	1039	885	398	1204	644	5176
6	973	1010	853	325	1149	607	4917
8	995	1028	875	395	1193	581	5067
11	970	1038	883	424	1161	562	5038
17	985	1042	674	390	1171	577	4839
19	943	1031	841	396	1196	543	4950
26	942	1046	858	349	1184	628	5007
37	–	–	840	385	–	–	1225
44	907	854	807	386	1196	543	4693
Total	9490	9823	9231	4195	11554	5834	50127

Prepupae were located in 20.3% of cells in the outer nesting areas as compared to 20.4% in the inner (Appendix G, Table LXIV). In the upper and lower nesting areas, prepupae were located in 21.1 and 19.5% of the cells, respectively (Appendix G, Table LXVII). In the left and right nesting areas, prepupae were located in 21.0 and 19.8%, respectively, of the cells (Appendix G, Table LXX).

CHAPTER V

DISCUSSION

Results were highly variable for numbers of bees and cells removed per field. This was partially due to field conditions. The second group of bees set out in the later three fields was subjected to initially warmer temperatures than the first group. With the exception of field A2, which was irrigated, these later placed bees tended not to provision as many nests. Nectar secretion may have diminished and there tended to be an accelerated period of bloom loss due to dry conditions in the nonirrigated fields. There was also an apparent high degree of interaction between fields and weeks, as individual fields contained various percentage rankings of bee emergence at the same sampling weeks. Second generation bee nesting activity curtailed sharply soon after these bees emerged in four fields. Two residual field bee populations remained active slightly longer where limited bloom persisted, although no significant nesting activity was seen.

Length of time in field from 8 to 44 weeks had no significant effect on subsequent spring adult bee emergence on cells tested. This differs from current literature which recommends placing alfalfa leafcutting bee cells into cold

storage at the end of the pollinating season or when low temperatures persist. Richards (1984) recommended storing cells at 20°C for 10-14 days for completion of feeding and larval development to the overwintering pupal stage, and then gradual cooling before cold storage. But Krunic (1972) and Johansen et al. (1973) found that the earlier produced eggs in the season overwhelmingly develop into second-generation emergent bees. It is not surprising, then, that there was almost no bee emergence from cells sampled at weeks two and three.

It was detrimental to remove cells the first few weeks after field release, due to insufficent time for diapause development and its destruction of life stage development of bees that would emerge as second-generation adults. This is consistent with the findings of Krunic (1972) and Johansen and Eves (1973). There was almost no bee emergence from cells brought in to cold storage after being in the field only two, three, and four weeks. Although radiographs indicate a large number of prepupae, most of these were not in diapause, but would have emerged as second generation adults if left in the field. After emergence of the second generation bees, prepupae in remaining cells were in diapause and yielded a higher percentage of adults from cells held through the winter.

The large percentage of females emerging from the basal cell position (89.2%) compared to males, and the large percentage of males (97.9%) compared to females in the 9th

cell position was indicative of female-egg laying patterns within nesting tunnels. Female leafcutting bees layed mostly female eggs in the first few cells, and then mostly male eggs toward the apical end of the nesting straw. This tendency has been reported in the literature (Hobbs 1973; Gerber and Klostermeyer 1972; Rothschild 1979). A 1:1.5 sex ratio of females to males was found. The literature reports a variable sex ratio, but a 1:2 and a 1:3 female to male ratio is most common according to Tirgari (1963), Osgood (1964), Stephen and Torchio (1965), and Waters (1969). Johansen et al. (1979) did report a 1:1 ratio, or even higher female ratio sometimes occurring, which is similar to the sex ratio reported in this study.

Tirgari (1963), Johansen and Eves (1973), and Pankiw et al. (1980) found that the longer diapausing larvae were kept in cold storage, the earlier the onset of emergence after incubation. While this study shows the same trends, apparently the cold period does not have to be kept at a constant temperature for this to occur, as evidenced by bee emergence from samples left in the field throughout the year. Most parasites (81.4%) were found in the basal cell position over the 44-week study. This indicates that parasites can enter the nesting area through small openings in the carton backs. Obstructing parasite access to this area may significantly reduce parasitism. Parasites were mainly found at weeks 17 through 26. They apparently were in diapause along with the leafcutting bees. Predators were

found in similar numbers in cells removed at each week sampling period. This was due to diversity of species and life cycles.

There was no significant difference in nesting straw positions (outer-inner, upper-lower, and left-right) and bee emergence within a shelter over the study period, due to high variability. There were apparently no nesting areas that were more adversely exposed to abiotic or biotic factors.

The number of filled nesting straws is not a good indication of population fluctuations. Initial increase in nesting straws filled (capped) is greatly reduced as second-generation bees emerge through cell caps. Except for a minor peak due to limited second-generation nesting activity (females recapping some nesting straws), filled-straw counts steadily declined, even though bee emergence rates over the same periods increased. Filled-straw counts, however, definitely indicate period of second-generation bee emergence, due to marked decrease in capped-off straws as a result of bee emergence (Figure 16).

The number of prepupae during the first four weeks, as determined by X-ray analysis, and number of emerging bees show inverse trends. This discrepancy between high numbers of prepupae and low numbers of emerging bees is due to the large percentage of prepupae that are not in diapause, but continue to develop. Beginning at the 6th week, the number of bees emerging increases in relative proportion to the

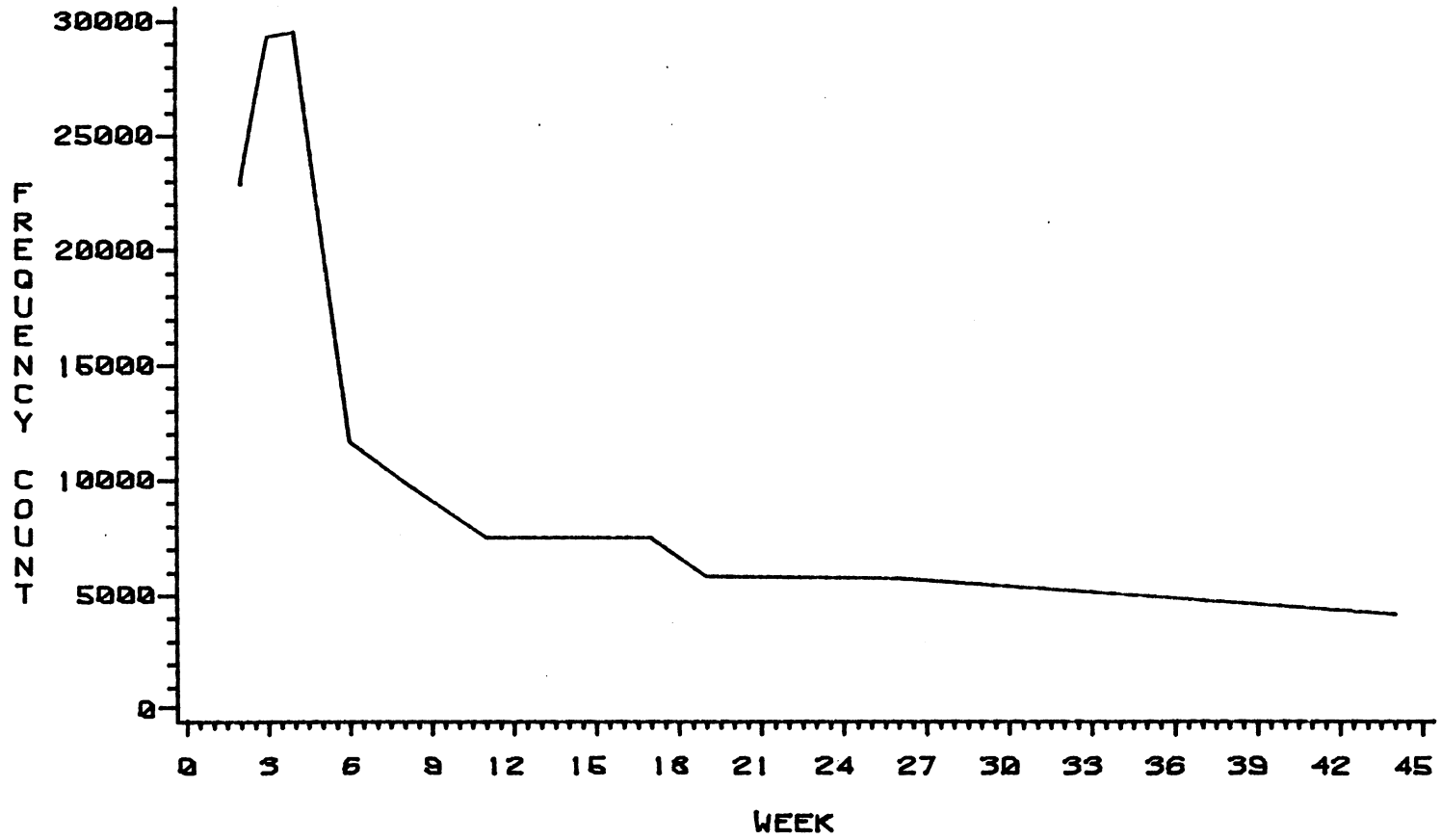

Figure 16. Filled Nesting Straws at Various Weeks Within Six Alfalfa Leafcutting Bee Shelters at Six Alfalfa Fields in Woodward County, Oklahoma, 1983-84

number of prepupae up to the 11th week (Figure 17). Number of prepupae from the 6th to the 11th week, as revealed by X-ray analysis, may be a quick and efficient method to estimate overwintering survival of bee populations.

The slightly lower bee emergence from those cells which were subjected to X-rays is not of practical importance. Three of the eleven weeks in which samples were taken actually had a higher percent bee emergence from cells that were subjected to X-ray. Any overall slight detriment to bee emergence is possibly due to the period the cells were removed from cold storage than that caused by X-ray application.

Disease was a high mortality factor on cell samples collected over most of the study period (ca. 30%). More recent losses caused by chalkbrood fungus disease have been reported in the literature to average 40 to 50% in Oregon, Idaho, and Nevada (Johansen et al. 1979). The percentage of disease, therefore, found in this study is not abnormally high and is consistent with what is found in other locations. Briggs and Thorp (1982) did report an increase in chalkbrood as the season progressed. In this study there was no such trend. Empty cells were cells out of which bees had already emerged, and accounted for about 30% of the nonemergence factors.

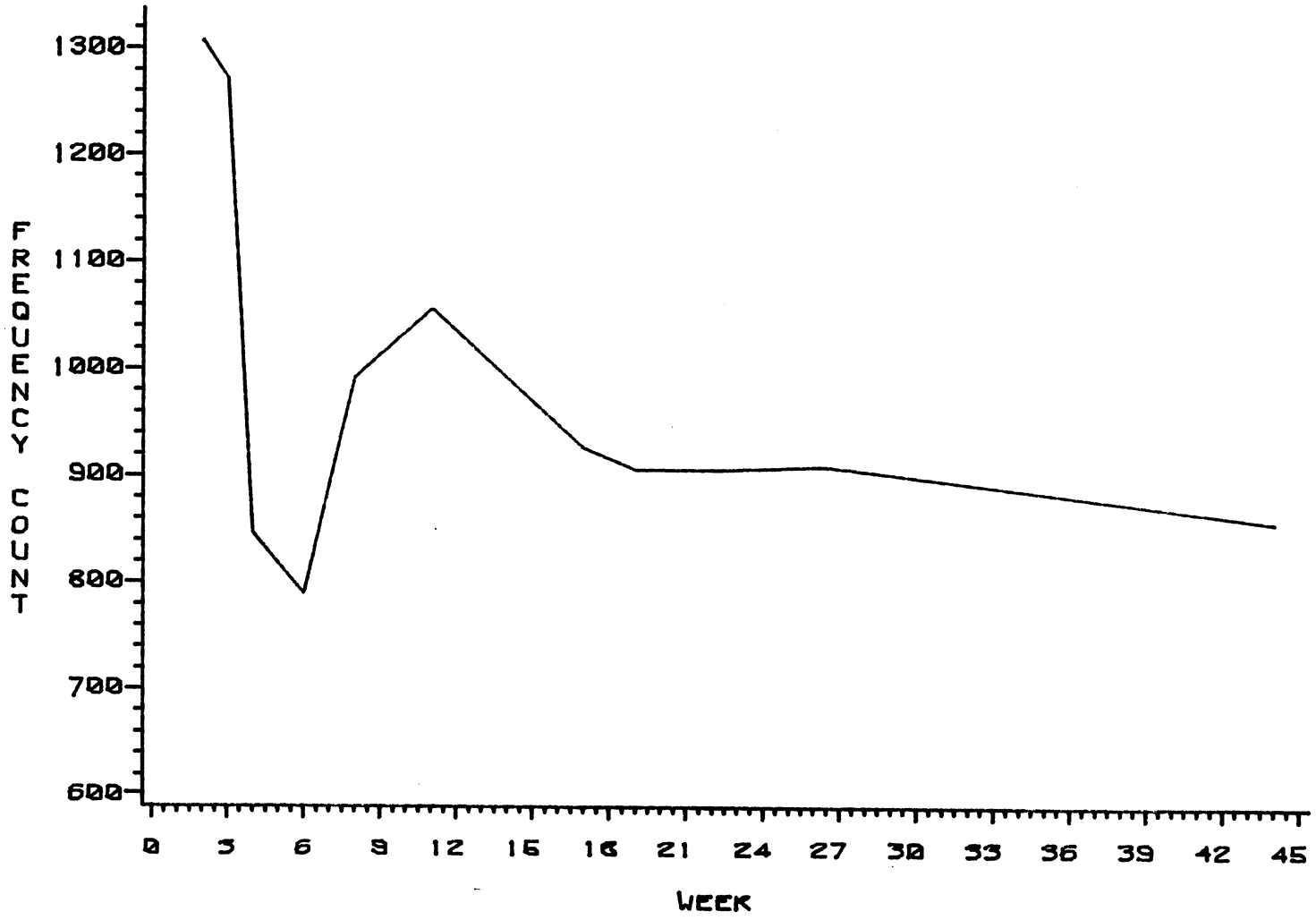

Figure 17. Alfalfa Leafcutting Bee Prepupae Determined by X-Ray Analysis of Nesting Straw Samples Removed at Various Weeks from Six Alfalfa Fields, Woodward County, Oklahoma, 1983-84

CHAPTER VI

SUMMARY AND CONCLUSIONS

This study was undertaken to determine optimal times for removal of alfalfa leafcutting bee cells from field shelters and placing them in cold storage facilities for maximum overwintering success. Parasitism, predation, disease, and cell position also were determined for the various cell-removal times. Field cells placed in cold storage from week eight to week 44 showed no significant difference in subsequent bee emergence. Cell removal up to the first eight weeks after field release was definitely detrimental to subsequent bee emergence.

While usual management practice is to remove cells from alfalfa seed fields after pollination has been accomplished, or, as in Oklahoma, about time of first frost, this study showed no significant effect on adult overwintering survival if cells were removed earlier (eight weeks after initial field release), or later (44 weeks).

Disease was responsible for 32.7% of the non-bee emergence factors. Effective treatment and control of spore formation on nesting material should be attempted to reduce incidence of disease. Although there were very few parasites or predators found in cell samples, parasite and

predator damaged cells occurred in over 12% of the cells. The basal cell position contained 80.3% of the parasites found. Effective control during incubation and shelter design to help reduce nest access should be practiced.

Larval mortality occurred in about 25% of the samples. High temperatures may have had an influence, as reported by Bohart et al. (1976).

Other findings made from this study were:

1. The emergence ratio of females to males was 1 : 1.15 over the sampling period.

2. Eighty-nine percent of the bees emerging from the basal cell position were female, while only 2.6% of the bees emerging from the 4 most apical cells were female.

3. Although there was a high variability in the number of bees emerging in samples removed among the fields, there was no significant difference in the nesting positions within a shelter. There were, however, significantly more cells constructed in the upper nesting areas than in the lower.

4. X-ray processing of nesting straw samples had a slight detrimental effect on bee emergence. Further testing should be done on influence of temporarily removing cells from cold storage, and its effect on bee emergence rates.

5. Filled nesting straw counts fluctuated and were not a good estimation of successful overwintering survival trends as measured by bee emergence of overwintered cells. They do, however, indicate period of second-generation field

emergence.

6. Prepupa numbers as determined by X-ray analysis indicate subsequent overwintering survival trends only of cells removed during the period of six to 11 weeks after the initial field release of bees.

This study examined effects of cell removal times on overwintering survival of alfalfa leafcutting bees. Continued research efforts in this area are encouraged to shed more light on ways to successfully manage this useful insect pollinator to obtain maximum propagation under local conditions from year to year.

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APPENDIXES

APPENDIX A

ADULT ALFALFA LEAFCUTTING BEE TABLES

TABLE XXII

NUMBER OF ALFALFA LEAFCUTTING BEE CELLS REMOVED FROM SIX ALFALFA FIELDS AT VARIOUS WEEK INTERVALS, PLACED IN COLD STORAGE, AND LATER INCUBATED TO DETERMINE ADULT VIABILITY, INCIDENCE OF PARASITISM AND PREDATION, WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Field						Total
	A1	A2	C1	C2	S1	S2	
2	971	246	1010	121	1313	572	4233
3	906	832	742	533	1418	609	5040
4	916	1108	1008	402	1385	593	5412
6	560	1060	1189	470	827	235	4341
8	580	913	717	441	1069	562	4282
11	1226	1078	1166	407	422	309	4608
17	1091	920	570	625	873	686	4765
19	1275	539	694	399	1656	422	5005
26	545	1131	627	430	458	358	3549
37	-	-	1196	451	-	-	1647
44	523	474	958	164	791	363	3273
Total	8593	8301	9877	4443	10212	4729	46155

TABLE XXIII

NUMBER OF ADULT ALFALFA LEAFCUTTING BEES EMERGING FROM SIX NESTING CARTONS WITHIN A SHELTER AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Carton						Total
	A	B	C	D	E	F	
2	0	0	0	0	1	0	1
3	15	1	7	21	12	0	56
4	8	23	29	24	41	0	125
6	79	16	127	58	84	0	364
8	51	120	121	112	66	25	495
11	91	122	174	126	216	4	733
17	290	251	5	199	93	42	880
19	117	244	82	165	221	15	844
26	38	159	132	126	79	40	574
37	33	63	71	23	20	-	210
44	95	88	0	64	174	0	421
Total	817	1087	748	918	1007	126	4703

TABLE XXIV

NUMBER OF ALFALFA LEAFCUTTING BEE CELLS REMOVED FROM SIX NESTING CARTONS WITHIN A SHELTER FROM SIX ALFALFA FIELDS, PLACED IN COLD STORAGE, AND LATER INCUBATED TO DETERMINE ADULT VIABILITY, INCIDENCE OF PARASITISM, AND PREDATION, WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Carton						Total
	A	B	C	D	E	F	
2	1126	988	673	752	694	0	4233
3	1017	1296	242	1278	827	380	5040
4	656	1350	1045	1066	975	320	5412
6	901	429	833	845	1265	68	4341
8	580	941	970	1048	362	381	4282
11	597	886	1075	830	972	248	4608
17	1240	1509	79	1025	728	184	4765
19	790	1226	816	802	1067	304	5005
26	573	969	780	537	369	321	3549
37	350	374	340	314	269	–	1647
44	835	1100	0	429	909	0	3273
Total	8665	11068	6853	8926	8437	2206	46155

TABLE XXV

PERCENTAGE OF ADULT ALFALFA LEAFCUTTING BEES PER CELLS AS INFLUENCED BY CELL REMOVAL TIME FROM SIX NESTING CARTONS WITHIN A SHELTER AT SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Carton						Average Percent
	A	B	C	D	E	F	
2	0.00	0.00	0.00	0.00	0.14	0.00	0.02
3	1.47	0.08	2.89	1.64	1.45	0.00	1.11
4	1.22	1.70	2.77	2.25	4.20	0.00	2.31
6	8.77	3.73	15.25	6.86	6.64	0.00	8.38
8	8.79	12.75	12.47	10.69	18.23	6.56	11.56
11	15.24	13.77	16.19	15.18	22.20	1.61	15.91
17	23.39	16.63	6.33	19.41	12.77	22.83	18.47
19	14.81	19.90	10.05	20.57	20.71	4.93	16.86
26	6.63	16.41	16.92	23.46	21.41	12.46	16.17
37	9.43	16.84	20.88	7.32	7.43	—	12.75
44	11.37	8.00	0.00	14.92	19.14	0.00	12.86
Average Percent	9.43	9.82	10.91	10.28	11.93	5.71	10.19

TABLE XXVI

ALFALFA LEAFCUTTING BEES EMERGING FROM SIX NESTING CARTONS WITHIN A SHELTER AT SIX ALFALFA FIELDS AFTER COLD STORAGE AND INCUBATION

Field	Carton						Total
	A	B	C	D	E	F	
A1	72	101	38	145	175	14	545
A2	170	361	318	380	379	85	1693
C1	241	234	206	86	314	–	1081
C2	40	128	32	69	6	–	275
S1	231	236	119	217	84	27	914
S2	63	27	35	21	49	–	195
Total	817	1087	748	918	1007	126	4703

TABLE XXVII

ALFALFA LEAFCUTTING BEE CELLS FROM SIX NESTING CARTONS WITHIN A SHELTER AT SIX ALFALFA FIELDS AFTER COLD STORAGE AND INCUBATION

Field	Carton						Total
	A	B	C	D	E	F	
A1	996	2128	1214	2077	1660	518	8593
A2	879	2452	1304	1760	1579	327	8301
C1	2020	2183	1776	1629	2269	—	9877
C2	1064	1622	460	961	274	62	4443
S1	2374	1484	1492	2009	1554	1299	10212
S2	1332	1199	607	490	1101	—	4729
Total	8665	11068	6853	8926	8437	2206	46155

TABLE XXVIII

OUTER VERSUS INNER SHELTER NESTING POSITIONS OF ALFALFA LEAFCUTTING BEES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	OUTER							INNER							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Outer	A1	A2	C1	C2	S1	S2	Inner	Total
2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
3	10	14	9	0	6	0	39	6	0	3	0	8	0	17	56
4	1	51	10	3	0	12	77	0	41	2	5	0	0	48	125
6	5	126	49	0	2	26	208	2	103	35	15	1	0	156	364
8	1	63	99	18	32	26	239	26	68	42	21	52	22	231	470
11	55	143	136	12	27	13	386	54	142	110	19	9	9	343	729
17	70	106	61	7	116	21	381	89	154	35	48	115	16	457	838
19	49	78	59	23	164	10	383	90	78	40	37	189	12	446	829
26	14	164	60	23	28	14	303	18	155	29	4	25	0	231	534
37	--	--	98	9	--	--	107	--	--	93	10	--	--	103	210
44	18	82	50	14	30	9	203	23	40	61	7	82	5	218	421
Total	223	827	631	109	405	131	2326*	308	781	450	166	482	64	2251*	4577

*Outer not significantly different from inner at 0.05 level of probability (Paired T-test).

TABLE XXIX

OUTER VERSUS INNER SHELTER NESTING POSITIONS OF CELLS SAMPLED FROM SIX ALFALFA FIELDS AT VARIOUS WEEKS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	OUTER							INNER							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Outer	A1	A2	C1	C2	S1	S2	Inner	Total
2	476	110	475	65	681	331	2138	495	136	535	56	632	241	2095	4233
3	378	313	401	202	535	273	2102	445	483	341	269	684	336	2558	4660
4	379	550	513	240	559	336	2577	462	558	495	162	581	257	2515	5092
6	190	563	581	174	501	175	2184	302	497	608	296	326	60	2089	4273
8	158	379	453	215	352	316	1873	341	442	264	226	509	246	2028	3901
11	575	544	635	203	122	189	2268	651	534	531	204	43	120	2083	4351
17	507	316	278	265	349	333	2048	503	501	292	360	524	353	2533	4581
19	581	308	436	158	711	244	2418	621	231	258	241	714	218	2283	4701
26	289	511	292	239	138	210	1679	199	524	335	191	152	148	1549	3228
37	–	–	616	220	–	–	836	–	–	580	231	–	–	811	1647
44	255	301	477	93	371	226	1723	268	173	481	71	420	137	1550	3273
Total	3788	3895	5157	2074	4319	2613	21846*	4287	4079	4720	2307	4585	2116	22094*	43940

*Outer not significantly different from inner at 0.05 level of probability (Paired T-test).

TABLE XXX

UPPER VERSUS LOWER SHELTER NESTING POSITIONS OF ALFALFA LEAFCUTTING BEES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER							LOWER							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Upper	A1	A2	C1	C2	S1	S2	Lower	Total
2	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1
3	0	14	4	0	12	0	30	16	0	8	0	2	0	26	56
4	0	14	3	8	0	12	37	1	78	9	0	0	0	88	125
6	2	91	39	3	1	6	142	5	138	45	12	2	20	222	364
8	13	49	58	30	37	28	215	14	82	83	9	47	20	255	470
11	57	112	125	13	3	1	311	52	173	121	18	33	21	418	729
17	51	184	96	52	187	26	596	108	76	0	3	44	11	242	838
19	47	96	30	40	231	18	462	92	60	69	20	122	4	367	829
26	24	119	53	11	53	8	268	8	200	36	16	0	6	266	534
37	—	—	117	17	—	—	134	—	—	74	2	—	—	76	210
44	41	45	57	21	44	9	217	0	77	54	0	68	5	204	421
Total	235	724	582	195	569	108	2413*	296	884	499	80	318	87	2164*	4577

*Upper not significantly different from lower at 0.05 level of probability (Paired T-test).

TABLE XXXI

LEFT VERSUS RIGHT SHELTER NESTING POSITIONS OF ALFALFA LEAFUCTTING BEES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Week	LEFT Field A1	A2	C1	C2	S1	S2	Total Left	RIGHT Field A1	A2	C1	C2	S1	S2	Total Right	Grand Total
2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
3	9	13	9	0	2	0	33	7	1	3	0	12	0	23	56
4	1	43	1	0	0	8	53	0	49	11	8	0	4	72	125
6	0	177	27	10	1	17	232	7	52	57	5	2	9	132	364
8	8	83	22	11	68	42	234	19	48	119	28	16	6	236	470
11	39	108	123	23	36	10	339	70	177	123	8	0	12	390	729
17	24	143	61	31	126	29	414	135	117	35	24	105	8	424	838
19	52	0	33	16	179	0	280	87	156	66	44	174	22	549	829
26	13	128	77	11	0	7	236	19	191	12	16	53	7	298	534
37	–	–	110	3	–	–	113	–	–	81	16	–	–	97	210
44	31	0	37	0	66	0	134	10	122	74	21	46	14	287	421
Total	177	695	500	105	478	113	2068*	354	913	581	170	409	82	2509*	4577

*Left not significantly different from right at 0.05 level of probability (Paired T-test).

TABLE XXXII

LEFT VERSUS RIGHT SHELTER NESTING POSITIONS OF CELLS SAMPLED FROM SIX ALFALFA FIELDS AT VARIOUS WEEKS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	LEFT							RIGHT							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Left	A1	A2	C1	C2	S1	S2	Right	Total
2	626	0	369	121	664	389	2169	345	246	641	0	649	183	2064	4233
3	140	406	360	212	496	322	1936	683	390	382	259	723	287	2724	4660
4	416	393	319	121	720	243	2212	425	715	689	281	420	350	2880	5092
6	116	632	562	160	543	107	2120	376	428	627	310	284	128	2153	4273
8	124	408	215	224	711	396	2078	375	413	502	217	150	166	1823	3901
11	587	400	563	245	165	136	2096	639	678	603	162	0	173	2255	4351
17	119	439	271	282	453	262	1826	891	378	299	343	420	424	2755	4581
19	595	0	439	157	732	110	2033	607	539	255	242	693	332	2668	4701
26	247	396	547	227	0	217	1634	241	639	80	203	290	141	1594	3228
37	–	–	616	218	–	–	834	–	–	580	233	–	–	813	1647
44	267	0	378	0	431	0	1076	256	474	580	164	360	363	2197	3273
Total	3237	3074	4639	1967	4915	2182	20014*	4838	4900	5238	2414	3989	2547	23926*	43940

*Left not significantly different from right at 0.05 level of probability (Paired T-test).

APPENDIX B

FEMALE ALFALFA LEAFCUTTING BEE TABLES

TABLE XXXIII

NUMBER OF FEMALE ALFALFA LEAFCUTTING BEES EMERGING AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Field						Total
	A1	A2	C1	C2	S1	S2	
2	0	0	0	0	1	0	1
3	10	10	8	0	10	0	38
4	1	60	4	6	0	12	83
6	1	112	46	7	2	14	182
8	14	65	61	24	48	32	244
11	42	113	96	15	16	12	294
17	66	110	41	26	107	18	368
19	66	69	43	34	185	16	413
26	19	140	44	14	25	8	250
37	-	-	92	14	-	-	106
44	24	50	54	11	61	10	210
Total	243	729	489	151	455	122	2189

TABLE XXXIV

NUMBER OF FEMALE ALFALFA LEAFCUTTING BEES EMERGING FROM SIX NESTING CARTONS WITHIN A SHELTER AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Carton						Total
	A	B	C	D	E	F	
2	0	0	0	0	1	0	1
3	12	0	5	13	8	0	38
4	8	19	16	16	24	0	83
6	37	11	65	25	44	0	182
8	32	56	59	60	28	9	244
11	32	53	59	52	96	2	294
17	136	109	0	70	39	14	368
19	67	127	36	76	98	9	413
26	29	83	40	58	28	12	250
37	19	31	37	12	7	–	106
44	58	44	0	36	72	0	210
Total	430	533	317	418	445	46	2189

TABLE XXXV

ALFALFA LEAFCUTTING BEE FEMALES AND CELLS FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM OUTER AND INNER NESTING POSITIONS, WOODWARD COUNTY, OKLAHOMA, 1983-84

	OUTER			INNER		
Week	Total Cells	Females	Percent	Total Cells	Females	Percent
2	2138	0	0.0	2095	1	0.0
3	2102	26	1.2	2558	12	0.5
4	2577	48	1.9	2515	35	1.4
6	2184	105	4.8	2089	77	3.7
8	1873	120	6.4	2028	115	5.7
11	2268	164	7.2	2083	128	6.1
17	2048	164	8.0	2533	190	7.5
19	2418	190	7.9	2283	214	9.4
26	1679	133	7.9	1549	105	6.8
37	836	57	6.8	811	49	6.0
44	1723	99	5.7	1550	111	7.2
Total	21846	1106	5.1	22094	1037	4.7

TABLE XXXVI

OUTER VERSUS INNER SHELTER NESTING POSITIONS OF ALFALFA LEAFCUTTING BEE FEMALES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	OUTER							INNER							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Outer	A1	A2	C1	C2	S1	S2	Inner	Total
2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
3	4	10	6	0	6	0	26	6	0	2	0	4	0	12	38
4	1	30	4	1	0	12	48	0	30	0	5	0	0	35	83
6	1	61	28	0	1	14	105	0	51	18	7	1	0	77	182
8	1	30	39	12	21	17	120	9	30	22	12	27	15	115	235
11	22	60	51	10	12	9	164	20	53	45	5	2	3	128	292
17	33	38	31	3	51	8	164	32	59	10	23	56	10	190	354
19	24	31	22	15	91	7	190	42	38	21	19	85	9	214	404
26	7	65	32	11	10	8	133	9	69	12	3	12	0	105	238
37	–	–	52	5	–	–	57	–	–	40	9	–	–	49	106
44	9	36	23	7	18	6	99	15	14	31	4	43	4	111	210
Total	102	361	288	64	210	81	1106	133	344	201	87	231	41	1037	2143

TABLE XXXVII

ALFALFA LEAFCUTTING BEE FEMALES AND CELLS FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM UPPER AND LOWER NESTING POSITIONS, WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER			LOWER		
Week	Total Cells	Females	Percent	Total Cells	Females	Percent
2	2478	1	0.0	1755	0	0.0
3	2767	20	0.7	1893	18	1.0
4	2534	32	1.3	2558	51	2.0
6	1839	75	4.1	2434	107	4.4
8	1937	109	5.6	1964	126	6.4
11	1969	120	6.1	2382	172	7.2
17	3016	270	9.0	1565	84	5.4
19	2484	236	9.5	2217	168	7.6
26	1850	132	7.1	1378	106	7.7
37	904	67	7.4	743	39	5.2
44	2182	121	5.5	1091	89	8.2
Total	23960	1183	4.9	19980	960	4.8

TABLE XXXVIII

UPPER VERSUS LOWER SHELTER NESTING POSITIONS OF ALFALFA LEAFCUTTING BEE FEMALES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER							LOWER							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Upper	A1	A2	C1	C2	S1	S2	Lower	Total
2	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1
3	0	10	2	0	8	0	20	10	0	6	0	2	0	18	38
4	0	11	3	6	0	12	32	1	49	1	0	0	0	51	83
6	1	43	26	1	0	4	75	0	69	20	6	2	10	107	182
8	4	25	26	17	22	15	109	6	35	35	7	26	17	126	235
11	17	43	51	8	0	1	120	25	70	45	7	14	11	172	292
17	26	74	41	26	91	12	270	39	23	0	0	16	6	84	354
19	25	44	13	23	117	14	236	41	25	30	11	59	2	168	404
26	12	57	26	9	22	6	132	4	77	18	5	0	2	106	238
37	–	–	55	12	–	–	67	–	–	37	2	–	–	39	106
44	24	19	32	11	27	8	121	0	31	22	0	34	2	89	210
Total	109	326	275	113	288	72	1183	126	379	214	38	153	50	960	2143

TABLE XXXIX

ALFALFA LEAFCUTTING BEE FEMALES AND CELLS FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM LEFT AND RIGHT NESTING POSITIONS, WOODWARD COUNTY, OKLAHOMA, 1983-84

Week	Left			Right		
	Total Cells	Females	Percent	Total Cells	Females	Percent
2	2169	0	0.0	2064	1	0.0
3	1936	25	1.3	2724	13	0.5
4	2212	33	1.5	2880	50	1.7
6	2120	112	5.3	2153	70	3.3
8	2078	125	6.0	1823	110	6.0
11	2096	124	5.9	2255	168	7.5
17	1826	170	9.3	2755	184	6.7
19	2033	142	7.0	2668	262	9.8
26	1634	99	6.1	1594	139	8.7
37	834	60	7.2	813	46	5.7
44	1076	75	7.0	2197	135	6.1
Total	20014	965	4.8	23926	1178	4.9

TABLE XL

LEFT VERSUS RIGHT SHELTER NESTING POSITIONS OF ALFALFA LEAFCUTTING BEE FEMALES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	LEFT							RIGHT							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Left	A1	A2	C1	C2	S1	S2	Right	Total
2	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1
3	6	10	7	0	2	0	25	4	0	1	0	8	0	13	38
4	1	23	1	0	0	8	33	0	37	3	6	0	4	50	83
6	0	83	15	5	0	9	112	1	29	31	2	2	5	70	182
8	3	37	9	9	40	27	125	7	23	52	15	8	5	110	235
11	13	45	38	10	14	4	124	29	68	58	5	0	8	168	292
17	5	46	29	14	61	15	170	60	51	12	12	46	3	184	354
19	25	0	13	8	96	0	142	41	69	30	26	80	16	262	404
26	5	46	39	4	0	5	99	11	88	5	10	22	3	139	238
37	–	–	57	3	–	–	60	–	–	35	11	–	–	46	106
44	19	0	23	0	33	0	75	5	50	31	11	28	10	135	210
Total	77	290	231	53	246	68	965	158	415	258	98	195	54	1178	2143

TABLE XLI

MEAN EMERGENCE TIMES (DAYS) REQUIRED FOR FEMALE ALFALFA LEAFCUTTING BEES FROM CELLS BROUGHT IN AT VARIOUS WEEKS FROM SIX FIELDS AND INCUBATED AT CA. 28°C

Week	Field					
	A1	A2	C1	C2	S1	S2
2	–	–	–	–	24.00	–
3	26.43	31.29	32.25	–	26.44	–
4	41.00	29.75	37.17	29.08	–	28.03
6	33.00	29.43	31.18	29.67	36.00	27.29
8	27.81	30.60	27.80	27.99	28.92	29.23
11	26.94	28.40	28.14	26.86	26.47	28.45
17	28.73	26.88	28.14	26.08	26.66	26.18
19	30.06	29.83	28.05	25.11	27.63	28.38
26	28.38	27.18	28.87	26.76	26.58	26.81
37	–	–	26.82	25.16	–	–
44	22.99	24.58	23.30	22.20	22.73	22.53

APPENDIX C

MALE ALFALFA LEAFCUTTING BEE TABLES

TABLE XLII

NUMBER OF MALE ALFALFA LEAFCUTTING BEES EMERGING AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Field						Total
	A1	A2	C1	C2	S1	S2	
2	0	0	0	0	0	0	0
3	6	4	4	0	4	0	18
4	0	32	8	2	0	0	42
6	6	117	38	8	1	12	182
8	18	82	80	15	40	16	251
11	67	172	150	16	24	10	439
17	94	191	55	29	124	19	512
19	75	87	56	26	181	6	431
26	19	207	45	13	34	6	324
37	–	–	99	5	–	–	104
44	17	72	57	10	51	4	211
Total	302	964	592	124	459	73	2514

TABLE XLIII

NUMBER OF MALE ALFALFA LEAFCUTTING BEES EMERGING FROM SIX NESTING CARTONS WITHIN A SHELTER AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Carton						Total
	A	B	C	D	E	F	
2	0	0	0	0	0	0	0
3	3	1	2	8	4	0	18
4	0	4	13	8	17	0	42
6	42	5	62	33	40	0	182
8	19	64	62	52	38	16	251
11	59	69	115	74	120	2	439
17	154	142	5	129	54	28	512
19	50	117	46	89	123	6	431
26	9	76	92	68	51	28	324
37	14	32	34	11	13	-	104
44	37	44	0	28	102	0	211
Total	387	554	431	500	562	80	2514

TABLE XLIV

ALFALFA LEAFCUTTING BEE MALES AND CELLS FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM OUTER AND INNER NESTING POSITIONS, WOODWARD COUNTY, OKLAHOMA, 1983-84

	OUTER			INNER		
Week	Total Cells	Males	Percent	Total Cells	Males	Percent
2	2138	0	0.0	2095	0	0.0
3	2102	13	0.6	2558	5	0.2
4	2577	29	1.1	2515	13	0.5
6	2184	103	4.7	2089	79	3.8
8	1873	119	6.4	2028	116	5.7
11	2268	222	9.8	2083	215	10.3
17	2048	217	10.6	2533	267	10.5
19	2418	193	8.0	2283	232	10.2
26	1679	170	10.1	1549	126	8.1
37	836	50	6.0	811	54	6.7
44	1723	104	6.0	1550	107	6.9
Total	21846	1220	5.6	22094	1214	5.5

TABLE XLV

OUTER VERSUS INNER SHELTER NESTING POSITIONS OF ALFALFA LEAFCUTTING BEE MALES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, 1983-84

	OUTER							INNER							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Outer	A1	A2	C1	C2	S1	S2	Inner	Total
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	6	4	3	0	0	0	13	0	0	1	0	4	0	5	18
4	0	21	6	2	0	0	29	0	11	2	0	0	0	13	42
6	4	65	21	0	1	12	103	2	52	17	8	0	0	79	182
8	0	33	60	6	11	9	119	17	38	20	9	25	7	116	235
11	33	83	85	2	15	4	222	34	89	65	14	7	6	215	437
17	37	68	30	4	65	13	217	57	95	25	25	59	6	267	484
19	25	47	37	8	73	3	193	48	40	19	18	104	3	232	425
26	7	99	28	12	18	6	170	9	86	17	1	13	0	126	296
37	–	–	46	4	–	–	50	–	–	53	1	–	–	54	104
44	9	46	27	7	12	3	104	8	26	30	3	39	1	107	211
Total	121	466	343	45	195	50	1220	175	437	249	79	251	23	1214	2434

TABLE XLVI

ALFALFA LEAFCUTTING BEE MALES AND CELLS FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM UPPER AND LOWER NESTING POSITIONS, WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER			LOWER		
Week	Total Cells	Males	Percent	Total Cells	Males	Percent
2	2478	0	0.0	1755	0	0.0
3	2767	10	0.4	1893	8	0.4
4	2534	5	0.2	2558	37	1.4
6	1839	67	3.6	2434	115	4.7
8	1937	106	5.5	1964	129	6.6
11	1969	191	9.7	2382	246	10.3
17	3016	326	10.8	1565	158	10.1
19	2484	226	9.1	2217	199	9.0
26	1850	136	7.4	1378	160	11.6
37	904	67	7.4	743	37	5.0
44	2182	96	4.4	1091	115	10.5
Total	23960	1230	5.1	19980	1204	6.0

TABLE XLVII

UPPER VERSUS LOWER SHELTER NESTING POSITIONS OF ALFALFA LEAFCUTTING BEE MALES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER							LOWER							
	Field							Field							
Week	A1	A2	C1	C2	S1	S2	Total Upper	A1	A2	C1	C2	S1	S2	Total Lower	Grand Total
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	4	2	0	4	0	10	6	0	2	0	0	0	8	18
4	0	3	0	2	0	0	5	0	29	8	0	0	0	37	42
6	1	48	13	2	1	2	67	5	69	25	6	0	10	115	182
8	9	24	32	13	15	13	106	8	47	48	2	21	3	129	235
11	40	69	74	5	3	0	191	27	103	76	11	19	10	246	437
17	25	110	55	26	96	14	326	69	53	0	3	28	5	158	484
19	22	52	17	17	114	4	226	51	35	39	9	63	2	199	425
26	12	62	27	2	31	2	136	4	123	18	11	0	4	160	296
37	–	–	62	5	–	–	67	–	–	37	0	–	–	37	104
44	17	26	25	10	17	1	96	0	46	32	0	34	3	115	211
Total	126	398	307	82	281	36	1230	170	505	285	42	165	37	1204	2434

TABLE XLVIII

ALFALFA LEAFCUTTING BEE MALES AND CELLS FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM LEFT AND RIGHT NESTING POSITIONS, WOODWARD COUNTY, OKLAHOMA, 1983-84

	LEFT			RIGHT		
Week	Total Cells	Males	Percent	Total Cells	Males	Percent
2	2169	0	0.0	2064	0	0.0
3	1936	8	0.4	2724	10	0.4
4	2212	20	0.9	2880	22	0.8
6	2120	120	5.7	2153	62	2.9
8	2078	109	5.2	1823	126	6.9
11	2096	215	10.3	2255	222	9.8
17	1826	244	13.4	2755	240	8.7
19	2033	138	6.8	2668	287	10.8
26	1634	137	8.4	1594	159	10.0
37	834	53	6.4	813	51	6.3
44	1076	59	5.5	2197	152	6.9
Total	20014	1103	5.5	23926	1331	5.6

TABLE XLIX

LEFT VERSUS RIGHT SHELTER NESTING POSITIONS OF ALFALFA LEAFCUTTING BEE MALES EMERGING FROM FIELD CELLS REMOVED AT VARIOUS WEEKS FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Week	LEFT Field A1	A2	C1	C2	S1	S2	Total Left	RIGHT Field A1	A2	C1	C2	S1	S2	Total Right	Grand Total
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	3	3	2	0	0	0	8	3	1	2	0	4	0	10	18
4	0	20	0	0	0	0	20	0	12	8	2	0	0	22	42
6	0	94	12	5	1	8	120	6	23	26	3	0	4	62	182
8	5	46	13	2	28	15	109	12	25	67	13	8	1	126	235
11	26	63	85	13	22	6	215	41	109	65	3	0	4	222	437
17	19	97	32	17	65	14	244	75	66	23	12	59	5	240	484
19	27	0	20	8	83	0	138	46	87	36	18	94	6	287	425
26	8	82	38	7	0	2	137	8	103	7	6	31	4	159	296
37	–	–	53	0	–	–	53	–	–	46	5	–	–	51	104
44	12	0	14	0	33	0	59	5	72	43	10	18	4	152	211
Total	100	405	269	52	232	45	1103	196	498	323	72	214	28	1331	2434

TABLE L

MEAN EMERGENCE TIMES (DAYS) REQUIRED FOR MALE ALFALFA LEAFCUTTING BEES FROM CELLS BROUGHT IN AT VARIOUS WEEKS FROM SIX FIELDS AND INCUBATED AT CA. 28°C

Week	Field					
	A1	A2	C1	C2	S1	S2
2	–	–	–	–	–	–
3	23.50	31.67	28.00	–	25.00	–
4	–	29.34	33.19	29.00	–	–
6	32.17	27.99	29.42	30.20	27.00	26.00
8	27.34	28.76	25.58	26.32	27.43	27.62
11	25.92	26.14	25.18	24.45	24.35	24.61
17	24.53	24.57	25.08	25.10	24.88	24.32
19	26.71	25.99	25.06	23.27	26.03	25.33
26	26.95	24.44	25.92	24.39	22.75	24.33
37	–	–	23.85	25.11	–	–
44	20.86	21.54	20.71	19.00	19.98	20.00

APPENDIX D

PARASITE TABLES

TABLE LI

ALFALFA LEAFCUTTING BEE CELLS WITH PARASITES EMERGING* FROM SIX NESTING CARTONS WITHIN A SHELTER AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Carton					
	A	B	C	D	E	F
2	0	0	0	0	0	0
3	0	1	0	0	0	0
4	0	0	0	0	0	0
6	0	0	1	0	1	0
8	0	1	0	0	0	0
11	0	2	2	0	4	0
17	12	4	0	3	2	2
19	0	3	0	4	2	0
26	0	5	5	2	4	3
37	0	1	1	0	1	—
44	1	1	0	0	3	0
Total	13	18	9	9	17	5

*Average number of parasites emerging per cell = 22.5.

TABLE LII

ALFALFA LEAFCUTTING BEE CELLS AND CELLS WITH PARASITES FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM OUTER AND INNER NESTING POSITIONS OF SIX SHELTERS

	Outer			Inner		
	Total Cells	Cells with Parasites	Percent	Total Cells	Cells with Parasites	Percent
2	2138	0	0.00	2095	0	0.00
3	2102	0	0.00	2558	1	0.04
4	2577	0	0.00	2515	0	0.00
6	2184	2	0.09	2089	0	0.00
8	1873	1	0.05	2028	0	0.00
11	2268	4	0.18	2083	4	0.19
17	2048	12	0.59	2533	9	0.36
19	2418	2	0.08	2283	7	0.31
26	1679	10	0.60	1549	6	0.39
37	836	3	0.36	811	0	0.00
44	1723	3	0.17	1550	2	0.13
Total	21846	37	0.17	22094	29	0.13

TABLE LIII

ALFALFA LEAFCUTTING BEE CELLS AND CELLS WITH PARASITES FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM UPPER AND LOWER NESTING POSITIONS OF SIX SHELTERS

	Upper			Lower		
Week	Total Cells	Cells with Parasites	Percent	Total Cells	Cells with Parasites	Percent
2	2478	0	0.00	1755	0	0.00
3	2767	1	0.04	1893	0	0.00
4	2534	0	0.00	2558	0	0.00
6	1839	1	0.05	2434	1	0.04
8	1937	1	0.05	1964	0	0.00
11	1969	5	0.25	2382	3	0.13
17	3016	17	0.56	1565	4	0.26
19	2484	4	0.16	2217	5	0.23
26	1850	8	0.43	1378	8	0.58
37	904	1	0.11	743	2	0.27
44	2182	2	0.09	1091	3	0.27
Total	23960	40	0.17	19980	26	0.13

TABLE LIV

ALFALFA LEAFCUTTING BEE CELLS AND CELLS WITH PARASITES FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM LEFT AND RIGHT NESTING POSITIONS OF SIX SHELTERS

	Left			Right		
Week	Total Cells	Cells with Parasites	Percent	Total Cells	Cells with Parasites	Percent
2	2169	0	0.00	2064	0	0.00
3	1936	0	0.00	2724	1	0.04
4	2212	0	0.00	2880	0	0.00
6	2120	1	0.05	2153	1	0.05
8	2078	0	0.00	1823	1	0.05
11	2096	2	0.10	2255	6	0.27
17	1826	13	0.71	2755	8	0.29
19	2033	2	0.10	2668	7	0.26
26	1634	6	0.37	1594	10	0.63
37	834	1	0.12	813	2	0.25
44	1076	1	0.09	2197	4	0.18
Total	20014	26	0.13	23926	40	0.17

APPENDIX E

PREDATOR TABLES

TABLE LV

ALFALFA LEAFCUTTING BEE PREDATORS EMERGING FROM SIX NESTING CARTONS WITHIN A SHELTER AFTER COLD STORAGE AND INCUBATION AS INFLUENCED BY CELL REMOVAL TIME FROM SIX ALFALFA FIELDS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

Weeks in Field	Carton					
	A	B	C	D	E	F
2	0	1	1	9	6	0
3	1	1	0	0	0	0
4	0	0	1	10	0	2
6	4	0	2	0	3	0
8	0	0	1	4	1	0
11	0	3	2	6	2	2
17	5	9	0	2	2	1
19	3	8	1	2	3	3
26	3	5	5	0	1	0
37	0	2	1	0	0	—
44	1	12	0	2	2	0
Total	17	41	14	35	20	8

TABLE LVI

ALFALFA LEAFCUTTING BEE CELLS AND PREDATORS EMERGING FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM OUTER AND INNER NESTING POSITIONS OF SIX SHELTERS

	Outer			Inner		
Week	Total Cells	Predators	Percent	Total Cells	Predators	Percent
2	2138	7	0.33	2095	10	0.48
3	2102	2	0.10	2558	0	0.00
4	2577	1	0.04	2515	10	0.40
6	2184	3	0.14	2089	6	0.29
8	1873	3	0.16	2028	3	0.15
11	2268	5	0.22	2083	8	0.38
17	2048	9	0.44	2533	9	0.36
19	2418	9	0.37	2283	8	0.35
26	1679	6	0.36	1549	8	0.52
37	836	1	0.12	811	2	0.25
44	1723	13	0.75	1550	4	0.26
Total	21846	59	0.27	22094	68	0.31

TABLE LVII

ALFALFA LEAFCUTTING BEE CELLS AND PREDATORS EMERGING FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM UPPER AND LOWER NESTING POSITIONS OF SIX SHELTERS

	Upper			Lower		
Week	Total Cells	Predators	Percent	Total Cells	Predators	Percent
2	2478	6	0.24	1755	11	0.63
3	2767	2	0.07	1893	0	0.00
4	2534	2	0.08	2558	9	0.35
6	1839	5	0.27	2434	4	0.16
8	1937	0	0.00	1964	6	0.31
11	1969	4	0.20	2382	9	0.38
17	3016	14	0.46	1565	4	0.26
19	2484	12	0.48	2217	5	0.23
26	1850	11	0.59	1378	3	0.22
37	904	2	0.22	743	1	0.13
44	2182	13	0.60	1091	4	0.37
Total	23960	71	0.30	19980	56	0.28

TABLE LVIII

ALFALFA LEAFCUTTING BEE CELLS AND PREDATORS EMERGING FROM SAMPLES REMOVED AT VARIOUS WEEKS FROM LEFT AND RIGHT NESTING POSITIONS OF SIX SHELTERS

	Left			Right		
Week	Total Cells	Predators	Percent	Total Cells	Predators	Percent
2	2169	7	0.32	2064	10	0.48
3	1936	1	0.05	2724	1	0.04
4	2212	7	0.32	2880	4	0.14
6	2120	6	0.28	2153	3	0.14
8	2078	2	0.10	1823	4	0.22
11	2096	6	0.29	2255	7	0.31
17	1826	5	0.27	2755	13	0.47
19	2033	5	0.25	2668	12	0.45
26	1634	8	0.49	1594	6	0.38
37	834	1	0.12	813	2	0.25
44	1076	2	0.19	2197	15	0.68
Total	20014	50	0.25	23926	77	0.32

APPENDIX F

FILLED NESTING STRAW COUNTS

TABLE LIX

OUTER AND INNER FILLED NESTING STRAW COUNTS OVER A 44-WEEK PERIOD AT SIX ALFALFA FIELDS, WOODWARD COUNTY, OKLAHOMA, 1983-84

Week	OUTER Field A1	A2	C1	C2	S1	S2	Outer Average	INNER Field A1	A2	C1	C2	S1	S2	Inner Average	Total Average
2	2657	2129	2208	558	2993	1523	2011	2524	1807	1795	474	3023	1213	1806	1909
3	3316	3245	2372	517	3505	1677	2439	3335	3173	2004	457	3540	1372	2314	2376
4	3137	3224	2183	535	3439	1627	2358	3114	3208	2064	430	3454	1337	2268	2313
6	810	1895	855	66	1159	244	838	814	1931	771	41	1099	185	807	822
8	490	1860	481	58	1655	177	787	487	1834	364	44	1562	117	735	761
11	457	1144	430	59	1284	153	588	484	1131	313	44	1228	122	554	571
17	357	1460	418	46	1210	148	607	359	1352	342	34	1124	104	553	580
19	311	1120	241	44	863	116	449	295	1127	207	31	810	91	427	438
26	324	1074	285	34	871	121	452	330	1014	231	32	811	82	417	434
37	—	—	248	41	—	—	48	—	—	201	27	—	—	38	43
44	301	751	142	26	791	119	355	247	625	124	18	658	75	291	323
Average	1105	1627	897	180	1615	537	994	1090	1564	765	148	1574	427	928	961

TABLE LX

UPPER AND LOWER FILLED NESTING STRAW COUNTS OVER A 44-WEEK PERIOD AT SIX ALFALFA FIELDS, WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER							LOWER							
	Field						Upper	Field						Lower	Total
Week	A1	A2	C1	C2	S1	S2	Average	A1	A2	C1	C2	S1	S2	Average	Average
2	2856	2361	2339	652	3244	1571	2171	2325	1575	1664	380	2772	1165	1647	1909
3	3364	3374	2540	612	3569	1767	2538	3287	3044	1836	362	3476	1282	2215	2376
4	3212	3308	2461	604	3464	1758	2468	3039	3124	1786	361	3429	1206	2158	2313
6	851	1985	883	82	1195	270	878	773	1841	743	25	1063	159	767	823
8	599	2073	516	79	1765	175	868	378	1621	329	23	1452	119	654	761
11	611	1431	410	76	1479	169	696	330	844	333	27	1033	106	446	571
17	520	1774	421	58	1464	135	729	196	1038	339	22	870	117	430	580
19	434	1460	318	60	1157	135	594	172	787	130	15	516	72	282	438
26	430	1392	346	56	1197	134	593	224	696	170	10	485	69	276	434
37	—	—	310	53	—	—	61	—	—	139	15	—	—	26	43
44	434	934	206	40	1020	131	461	114	442	60	4	429	63	185	323
Average	1210	1827	977	216	1778	568	1096	985	1365	684	113	1411	396	826	961

TABLE LXI

LEFT AND RIGHT FILLED NESTING STRAW COUNTS OVER A 44-WEEK PERIOD AT SIX ALFALFA FIELDS, WOODWARD COUNTY, OKLAHOMA, 1983-84

Week	LEFT Field A1	A2	C1	C2	S1	S2	Left Average	RIGHT Field A1	A2	C1	C2	S1	S2	Right Average	Total Average
2	2556	2301	1794	399	3245	1400	1949	2625	1635	2209	633	2771	1336	1868	1909
3	3222	3354	2052	425	3568	1532	2359	3429	3064	2324	549	3477	1517	2393	2376
4	3124	3317	2011	325	3475	1520	2295	3127	3115	2236	640	3418	1444	2330	2313
6	791	1903	772	62	1188	237	826	833	1923	854	45	1070	192	820	823
8	440	1916	390	40	1681	158	771	537	1778	455	62	1536	136	751	761
11	432	1181	332	35	1296	144	570	509	1094	411	68	1216	131	572	571
17	337	1503	379	30	1105	119	579	379	1309	381	50	1229	133	580	580
19	287	1219	190	24	830	106	443	319	1028	258	51	843	101	433	438
26	291	1092	242	18	879	109	439	363	996	274	48	803	94	430	434
37	—	—	200	20	—	—	37	—	—	249	48	—	—	50	43
44	270	736	125	16	750	108	334	278	640	141	28	699	86	312	323
Average	1068	1684	772	127	1638	494	964	1127	1507	890	202	1551	470	958	961

APPENDIX G

X-RAY ANALYSIS TABLES

TABLE LXII

ALFALFA LEAFCUTTING BEE PREPUPAE DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM SIX NESTING CARTONS WITHIN SIX SHELTERS

Week	Carton						Total
	A	B	C	D	E	F	
2	309	351	237	200	210	–	1307
3	297	257	225	225	242	25	1271
4	194	141	114	164	169	62	844
6	208	122	155	78	169	55	787
8	236	227	157	170	180	23	993
11	255	199	153	175	233	41	1056
17	283	180	160	163	96	42	924
19	196	238	135	146	174	15	904
26	183	173	159	154	195	45	909
37	13	45	48	24	26	–	156
44	185	155	186	147	166	16	855
Total	2359	2088	1729	1646	1860	324	10006

TABLE LXIII

ALFALFA LEAFCUTTING BEE CELLS DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM SIX NESTING CARTONS WITHIN SIX SHELTERS

Week	Carton						Total
	A	B	C	D	E	F	
2	979	1007	784	823	768	–	4361
3	1070	1073	701	884	869	257	4854
4	1060	1177	868	858	932	281	5176
6	972	1038	874	860	882	291	4917
8	989	1072	869	917	903	317	5067
11	1033	1034	851	906	914	300	5038
17	1030	1018	867	886	738	300	4839
19	985	1059	901	868	851	286	4950
26	1016	1001	885	896	907	302	5007
37	244	293	253	223	212	–	1225
44	926	957	880	795	864	271	4693
Total	10304	10729	8733	8916	8840	2605	50127

TABLE LXIV

ALFALFA LEAFCUTTING BEE CELLS AND PREPUPAE DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEK INTERVALS FROM OUTER AND INNER NESTING POSITIONS WITHIN SIX SHELTERS

	Outer			Inner		
Week	Total Cells X-Rayed	ALB Prepupae	Percent Prepupae	Total Cells X-Rayed	ALB Prepupae	Percent Prepupae
2	2214	676	30.5	2147	631	29.4
3	2328	613	26.3	2269	633	27.9
4	2499	441	17.6	2396	341	14.2
6	2373	414	17.4	2253	318	14.1
8	2443	455	18.6	2307	515	22.3
11	2447	514	21.0	2291	501	21.9
17	2223	425	19.1	2316	457	19.7
19	2404	433	18.0	2260	456	20.2
26	2360	440	18.6	2345	424	18.1
37	618	80	12.9	607	76	12.5
44	2276	427	18.8	2146	412	19.2
Total	24185	4918	20.3	23337	4764	20.4

TABLE LXV

ALFALFA LEAFCUTTING BEE PREPUPAE DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM OUTER AND INNER NESTING POSITIONS FROM SIX FIELD SHELTERS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	OUTER							INNER							
	Field						Outer	Field						Inner	Grand
Week	A1	A2	C1	C2	S1	S2	Total	A1	A2	C1	C2	S1	S2	Total	Total
2	77	65	111	66	254	103	676	124	62	112	91	147	95	631	1307
3	71	205	184	21	46	86	613	79	222	203	31	71	27	633	1246
4	27	232	122	25	7	28	441	56	134	104	11	20	16	341	782
6	23	189	130	2	25	45	414	23	179	72	6	9	29	318	732
8	39	174	91	27	103	21	455	59	204	78	15	144	15	515	970
11	72	163	97	23	144	15	514	46	223	95	24	104	9	501	1015
17	25	173	37	22	150	18	425	56	169	47	18	139	28	457	882
19	23	170	64	27	148	1	433	20	151	86	11	162	26	456	889
26	48	165	74	23	101	29	440	47	146	67	5	136	23	424	864
37	—	—	78	2	—	—	80	—	—	58	18	—	—	76	156
44	65	162	80	22	77	21	427	41	134	53	32	144	8	412	839
Total	470	1698	1068	260	1055	367	4918	551	1624	975	262	1076	276	4764	9682

TABLE LXVI

ALFALFA LEAFCUTTING BEE CELLS DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM OUTER AND INNER NESTING POSITIONS FROM SIX FIELD SHELTERS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	OUTER							INNER							
	Field						Total	Field						Total	Grand
Week	A1	S2	C1	C2	S1	S2	Outer	A1	A2	C1	C2	S1	S2	Inner	Total
2	452	404	409	185	488	276	2214	453	370	434	190	437	263	2147	4361
3	381	481	471	146	513	336	2328	435	460	401	178	521	274	2269	4597
4	482	511	469	210	508	319	2499	480	461	416	188	526	325	2396	4895
6	463	488	445	156	502	319	2373	453	454	408	169	481	288	2253	4626
8	465	479	443	228	504	324	2443	469	469	432	167	513	257	2307	4750
11	451	488	456	220	520	312	2447	460	460	427	204	490	250	2291	4738
17	464	477	330	175	489	288	2223	472	484	344	215	512	289	2316	4539
19	461	483	464	194	505	297	2404	439	483	377	202	513	246	2260	4664
26	434	483	441	174	490	338	2360	459	479	417	175	525	290	2345	4705
37	—	—	408	210	—	—	618	—	—	432	175	—	—	607	1225
44	440	421	413	195	511	296	2276	435	376	394	191	503	247	2146	4422
Total	4493	4715	4749	2093	5030	3105	24185	4555	4496	4482	2054	5021	2729	23337	47522

TABLE LXVII

ALFALFA LEAFCUTTING BEE CELLS AND PREPUPAE DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEK INTERVALS FROM UPPER AND LOWER NESTING POSITIONS WITHIN SIX SHELTERS

	Upper			Lower		
Week	Total Cells X-Rayed	ALB Prepupae	Percent Prepupae	Total Cells X-Rayed	ALB Prepupae	Percent Prepupae
2	2392	798	33.4	1969	509	25.9
3	2567	657	25.6	2030	589	29.0
4	2684	396	14.8	2211	386	17.5
6	2459	389	15.8	2167	343	15.8
8	2509	563	22.4	2241	407	18.2
11	2479	540	21.8	2259	475	21.0
17	2494	570	22.9	2045	312	15.3
19	2481	515	20.8	2183	374	17.1
26	2466	444	18.0	2239	420	18.8
37	671	73	10.9	554	83	15.0
44	2355	451	19.2	2067	388	18.8
Total	25557	5396	21.1	21965	4286	19.5

TABLE LXVIII

ALFALFA LEAFCUTTING BEE PREPUPAE DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM UPPER AND LOWER NESTING POSITIONS FROM SIX FIELD SHELTERS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER							LOWER							
	Field						Upper	Field						Lower	Grand
Week	A1	A2	C1	C2	S1	S2	Total	A1	A2	C1	C2	S1	S2	Total	Total
2	110	100	171	99	212	106	798	91	27	52	58	189	92	509	1307
3	67	215	216	45	47	67	657	83	212	171	7	70	46	589	1246
4	27	184	128	28	7	22	396	56	182	98	8	20	22	386	782
6	24	207	98	8	11	41	389	22	161	104	0	23	33	343	732
8	64	202	117	37	122	21	563	34	176	52	5	125	15	407	970
11	65	232	98	30	113	2	540	53	154	94	17	135	22	475	1015
17	44	232	64	22	184	24	570	37	110	20	18	105	22	312	882
19	27	205	68	13	180	22	515	16	116	82	25	130	5	374	889
26	43	165	69	7	134	26	444	52	146	72	21	103	26	420	864
37	—	—	64	9	—	—	73	—	—	72	11	—	—	83	156
44	55	145	88	49	103	11	451	51	151	45	5	118	18	388	839
Total	526	1887	1181	347	1113	342	5396	495	1435	862	175	1018	301	4286	9682

TABLE LXIX

ALFALFA LEAFCUTTING BEE CELLS DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM UPPER AND LOWER NESTING POSITIONS FROM SIX FIELD SHELTERS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	UPPER							LOWER							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Upper	A1	A2	C1	C2	S1	S2	Lower	Total
2	460	462	474	224	478	294	2392	445	312	369	151	447	245	1969	4361
3	484	503	470	235	543	332	2567	332	438	402	89	491	278	2030	4597
4	490	517	470	299	521	387	2684	472	455	415	99	513	257	2211	4895
6	464	502	451	211	492	339	2459	452	440	402	114	491	268	2167	4626
8	471	488	480	212	511	347	2509	463	460	395	183	506	234	2241	4750
11	456	513	456	223	512	319	2479	455	435	427	201	498	243	2259	4738
17	475	514	432	226	518	329	2494	461	447	242	164	483	248	2045	4539
19	479	510	474	211	510	297	2481	421	456	367	185	508	246	2183	4664
26	441	504	455	172	532	362	2466	452	458	403	177	483	266	2239	4705
37	—	—	455	216	—	—	671	—	—	385	169	—	—	554	1225
44	457	357	456	229	523	333	2355	418	440	351	157	491	210	2067	4422
Total	4677	4870	5073	2458	5140	3339	25557	4371	4341	4158	1689	4911	2495	21965	47522

TABLE LXX

ALFALFA LEAFCUTTING BEE CELLS AND PREPUPAE DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEK INTERVALS FROM LEFT AND RIGHT NESTING POSITIONS WITHIN SIX SHELTERS

	Left			Right		
Week	Total Cells X-Rayed	ALB Prepupae	Percent Prepupae	Total Cells X-Rayed	ALB Prepupae	Percent Prepupae
2	2172	661	30.4	2189	646	29.5
3	2188	618	28.2	2409	628	26.1
4	2369	380	16.0	2526	402	15.9
6	2263	411	18.2	2363	321	13.6
8	2334	463	19.8	2416	507	21.0
11	2349	502	21.4	2389	513	21.5
17	2334	525	22.5	2205	357	16.2
19	2311	409	17.7	2353	480	20.4
26	2354	438	18.6	2351	426	18.1
37	593	71	12.0	632	85	13.4
44	2177	435	20.0	2245	404	18.0
Total	23444	4913	21.0	24078	4769	19.8

TABLE LXXI

ALFALFA LEAFCUTTING BEE PREPUPAE DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM OUTER AND INNER NESTING POSITIONS FROM SIX FIELD SHELTERS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	LEFT							RIGHT							
	Field						Left	Field						Right	Right
Week	A1	A2	C1	C2	S1	S2	Total	A1	A2	C1	C2	S1	S2	Total	Total
2	82	95	87	73	219	105	661	119	32	136	84	182	93	646	1307
3	56	248	170	32	49	63	618	94	179	217	20	68	50	628	1246
4	47	193	87	15	5	33	380	36	173	139	21	22	11	402	782
6	11	223	86	1	22	68	411	35	145	116	7	12	6	321	732
8	41	178	52	20	138	34	463	57	200	117	22	109	2	507	970
11	54	185	85	30	133	15	502	64	201	107	17	115	9	513	1015
17	25	215	50	23	167	45	525	56	127	34	17	122	1	357	882
19	24	170	53	21	139	2	409	19	151	97	17	171	25	480	889
26	27	160	56	11	144	40	438	68	151	85	17	93	12	426	864
37	–	–	61	10	–	–	71	–	–	75	10	–	–	85	156
44	50	170	61	24	114	16	435	56	126	72	30	107	13	404	839
Total	417	1837	848	260	1130	421	4913	604	1485	1195	262	1001	222	4769	9682

TABLE LXXII

ALFALFA LEAFCUTTING BEE CELLS DETERMINED BY X-RAY ANALYSIS OF STRAW SAMPLES REMOVED AT VARIOUS WEEKS FROM LEFT AND RIGHT NESTING POSITIONS FROM SIX FIELD SHELTERS IN WOODWARD COUNTY, OKLAHOMA, 1983-84

	LEFT							RIGHT							
	Field						Total	Field						Total	Grand
Week	A1	A2	C1	C2	S1	S2	Left	A1	A2	C1	C2	S1	S2	Right	Total
2	449	416	394	162	478	273	2172	456	358	449	213	447	266	2189	4361
3	293	482	428	172	510	303	2188	523	459	444	152	524	307	2409	4597
4	481	490	423	133	505	337	2369	481	482	462	265	529	307	2526	4895
6	446	470	402	138	492	315	2263	470	472	451	187	491	292	2363	4626
8	448	494	427	160	524	281	2334	486	454	448	235	493	300	2416	4750
11	449	472	430	222	494	282	2349	462	476	453	202	516	280	2389	4738
17	468	492	418	170	509	277	2334	468	469	256	220	492	300	2205	4539
19	469	496	392	164	496	294	2311	431	470	449	232	522	249	2353	4664
26	432	503	417	147	502	353	2354	461	459	441	202	513	275	2351	4705
37	—	—	421	172	—	—	593	—	—	419	213	—	—	632	1225
44	433	396	376	172	519	281	2177	442	401	431	214	495	262	2245	4422
Total	4368	4711	4528	1812	5029	2996	23444	4680	4500	4703	2335	5022	2838	24078	47522

APPENDIX H

EXAMPLES OF RADIOGRAPHS

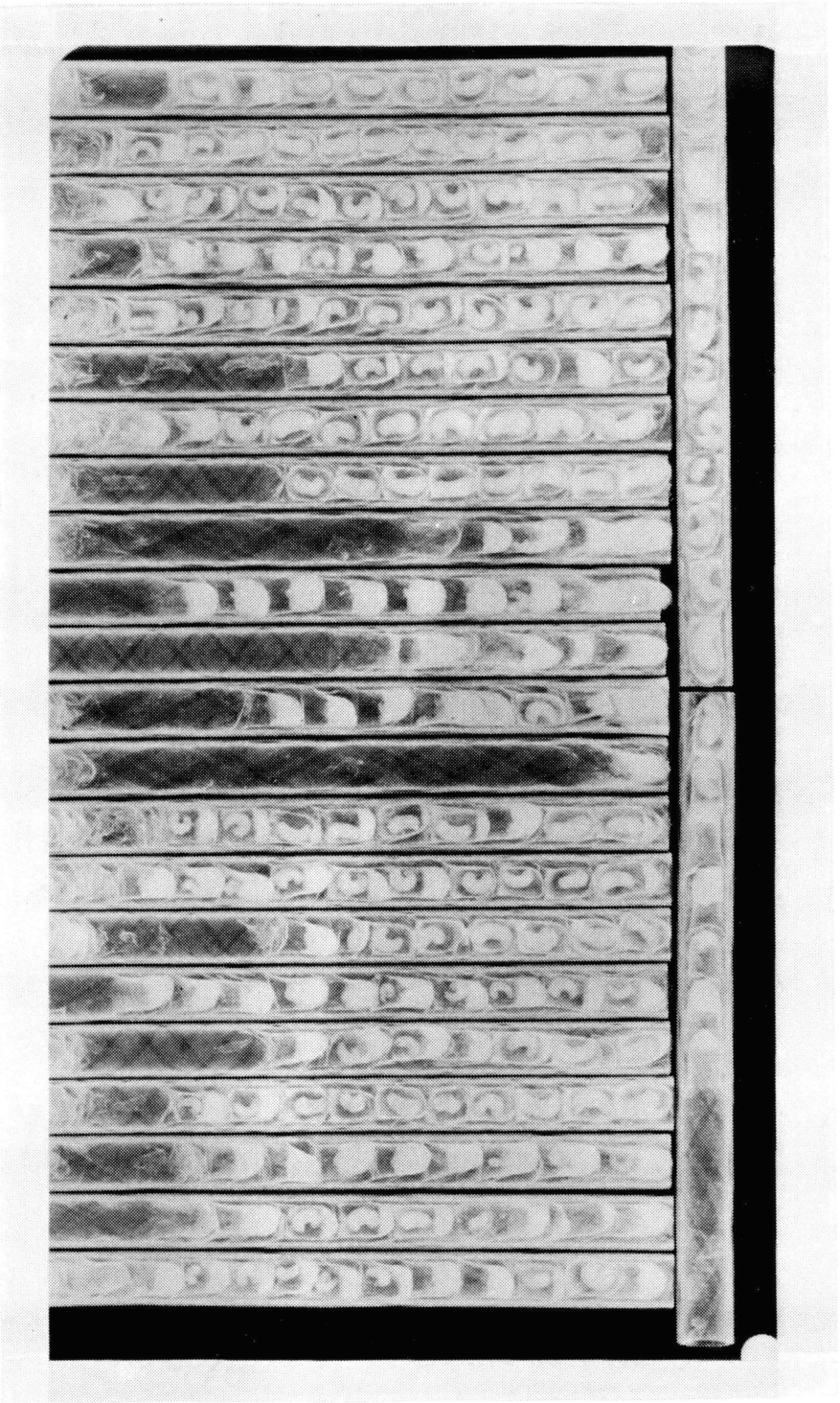

Figure 18. Week 2, Field S1, Carton D

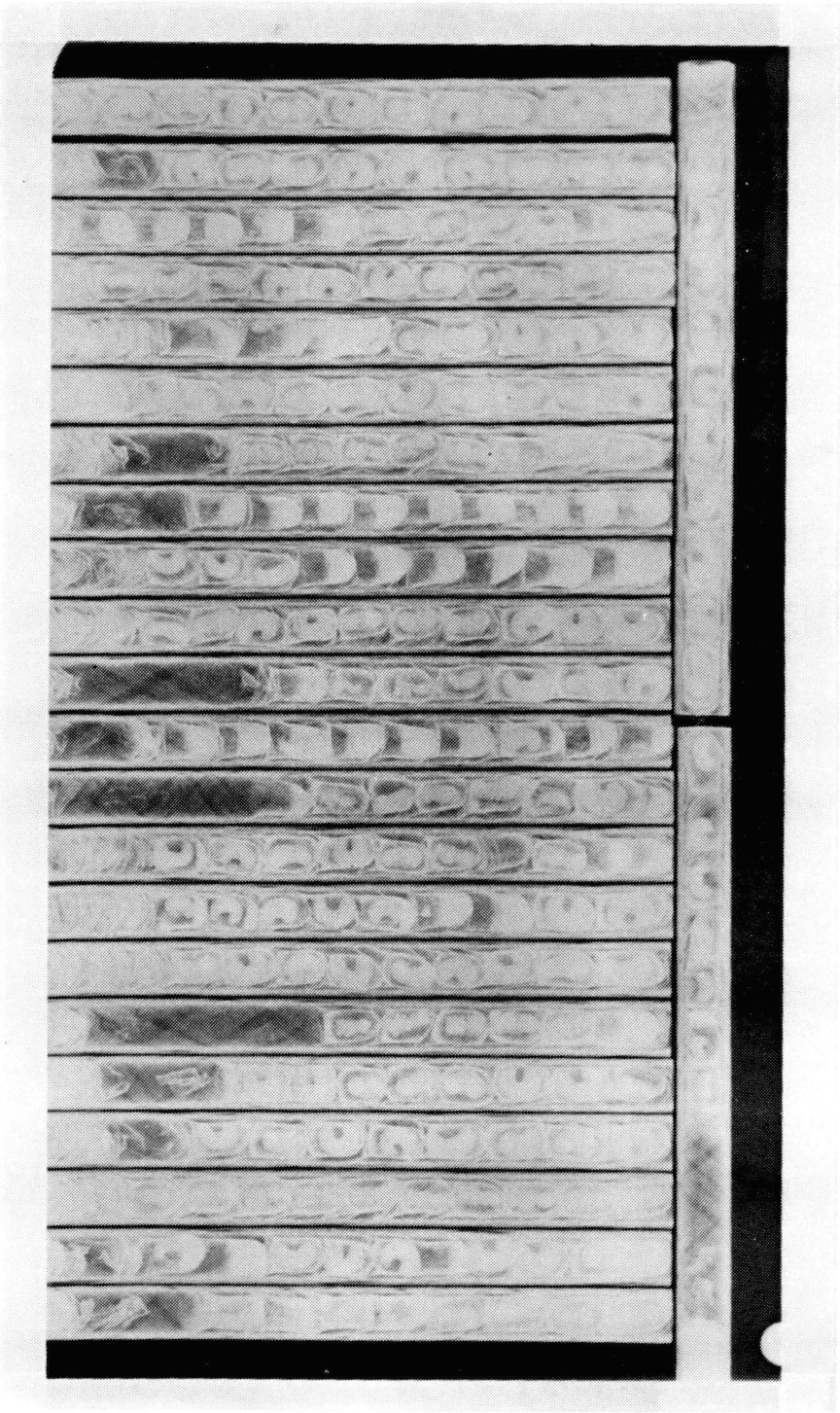

Figure 19. Week 3, Field A2, Carton A

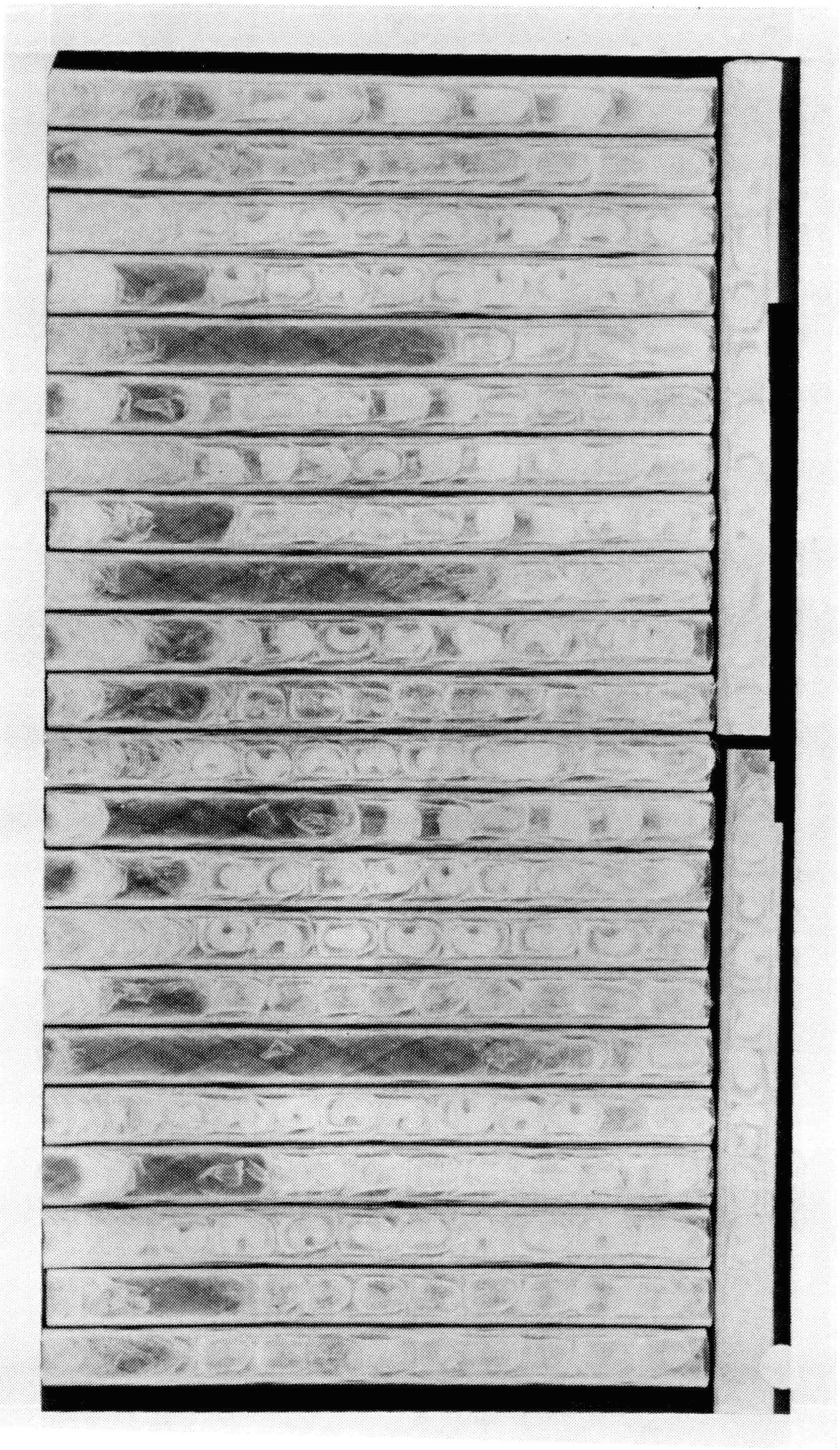

Figure 20. Week 4, Field A2, Carton E

Figure 21. Week 6. Field C1, Carton E

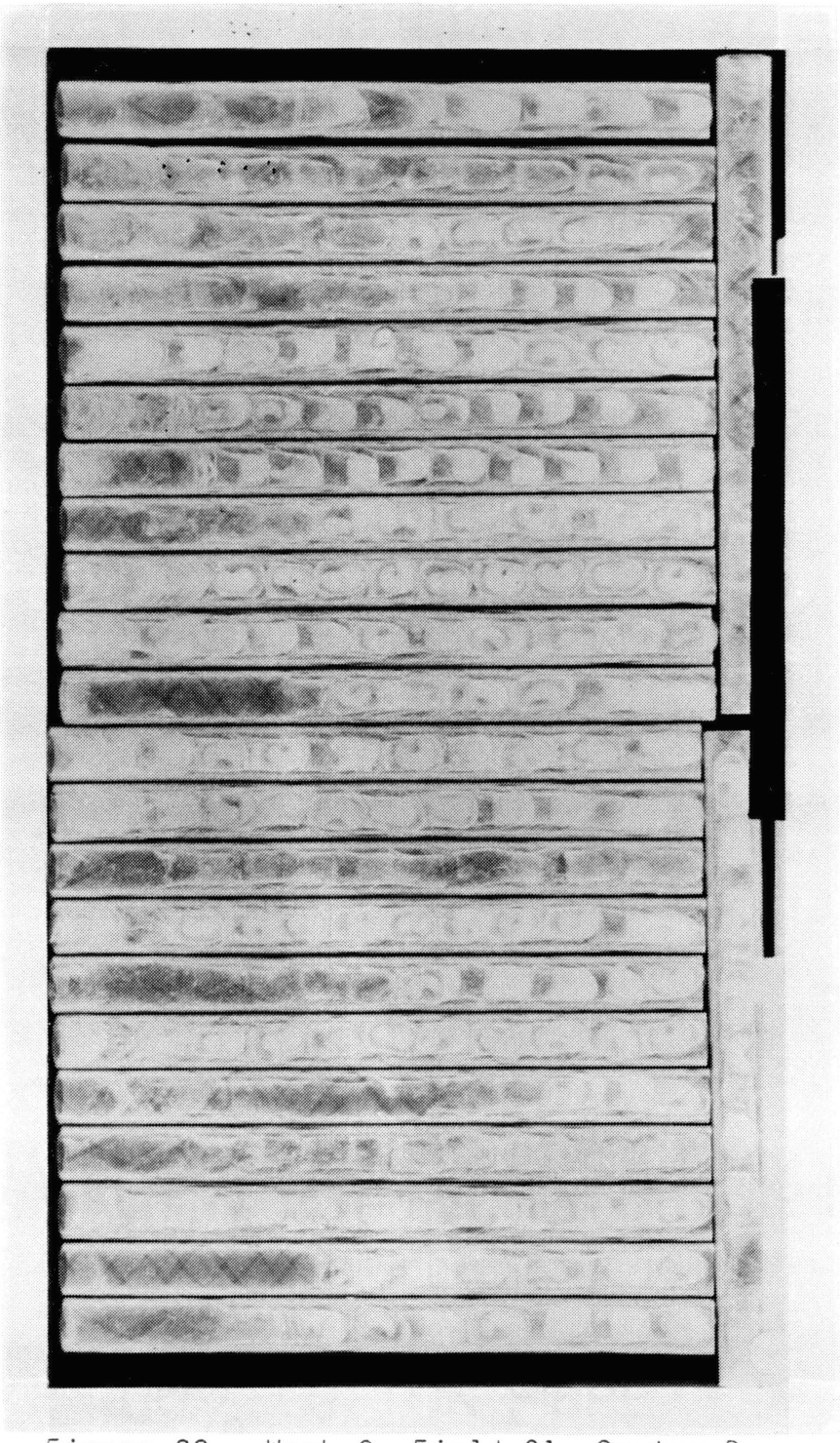

Figure 22. Week 8, Field S1, Carton D

Figure 23. Week 11, Field A2, Carton D

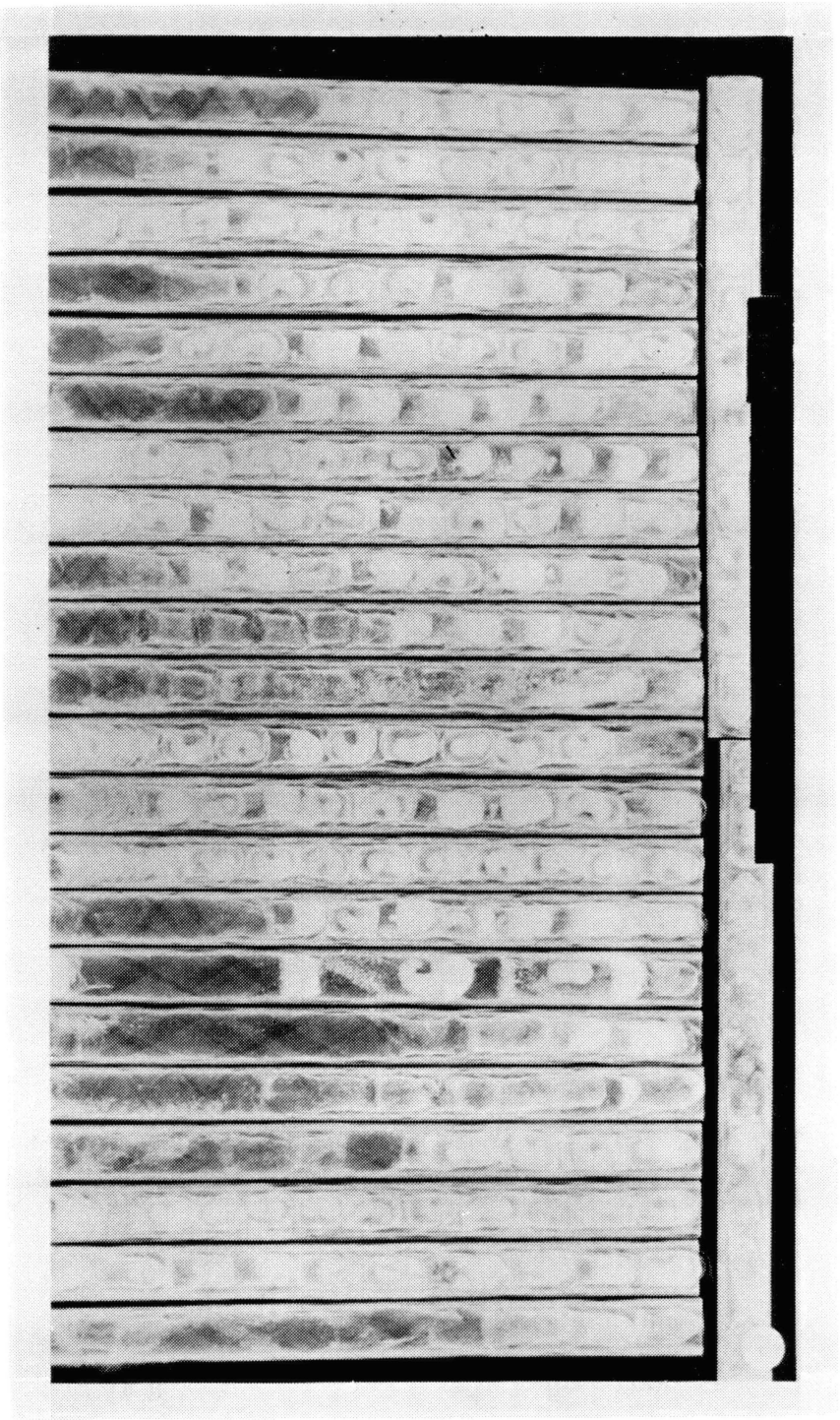

Figure 24. Week 17, Field S1, Carton B

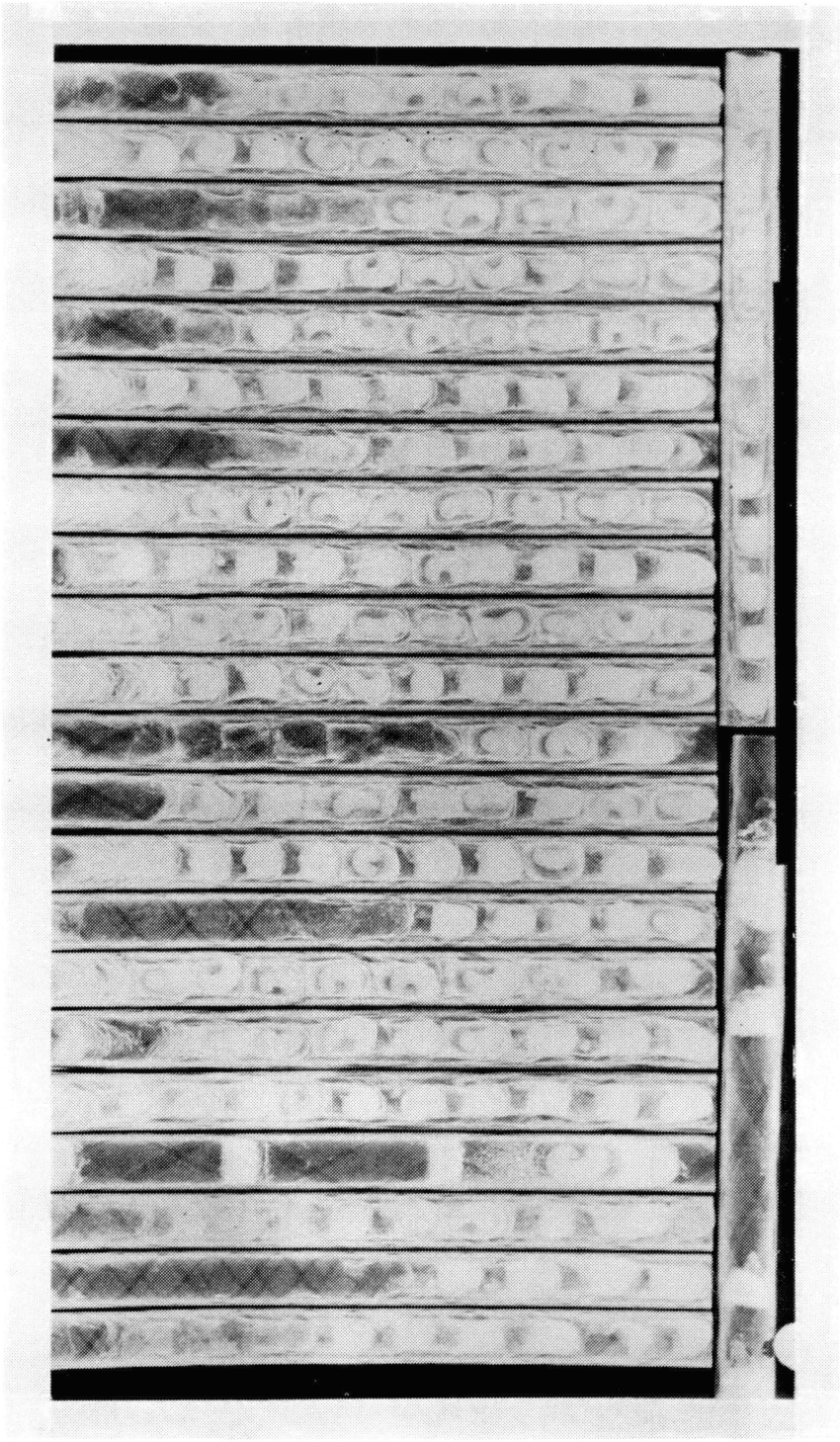

Figure 25. Week 19, Field S1, Carton A

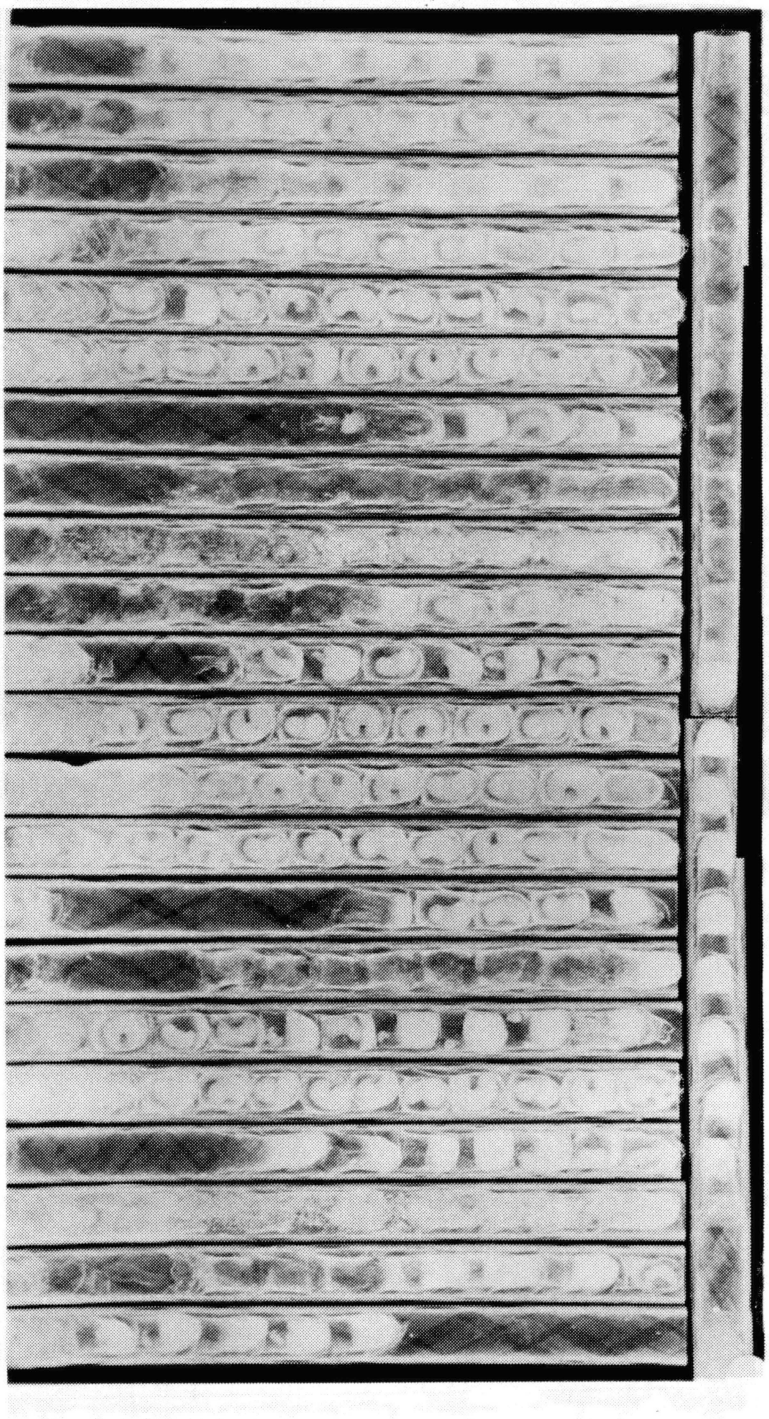

Figure 26. Week 26, Field A2, Carton B

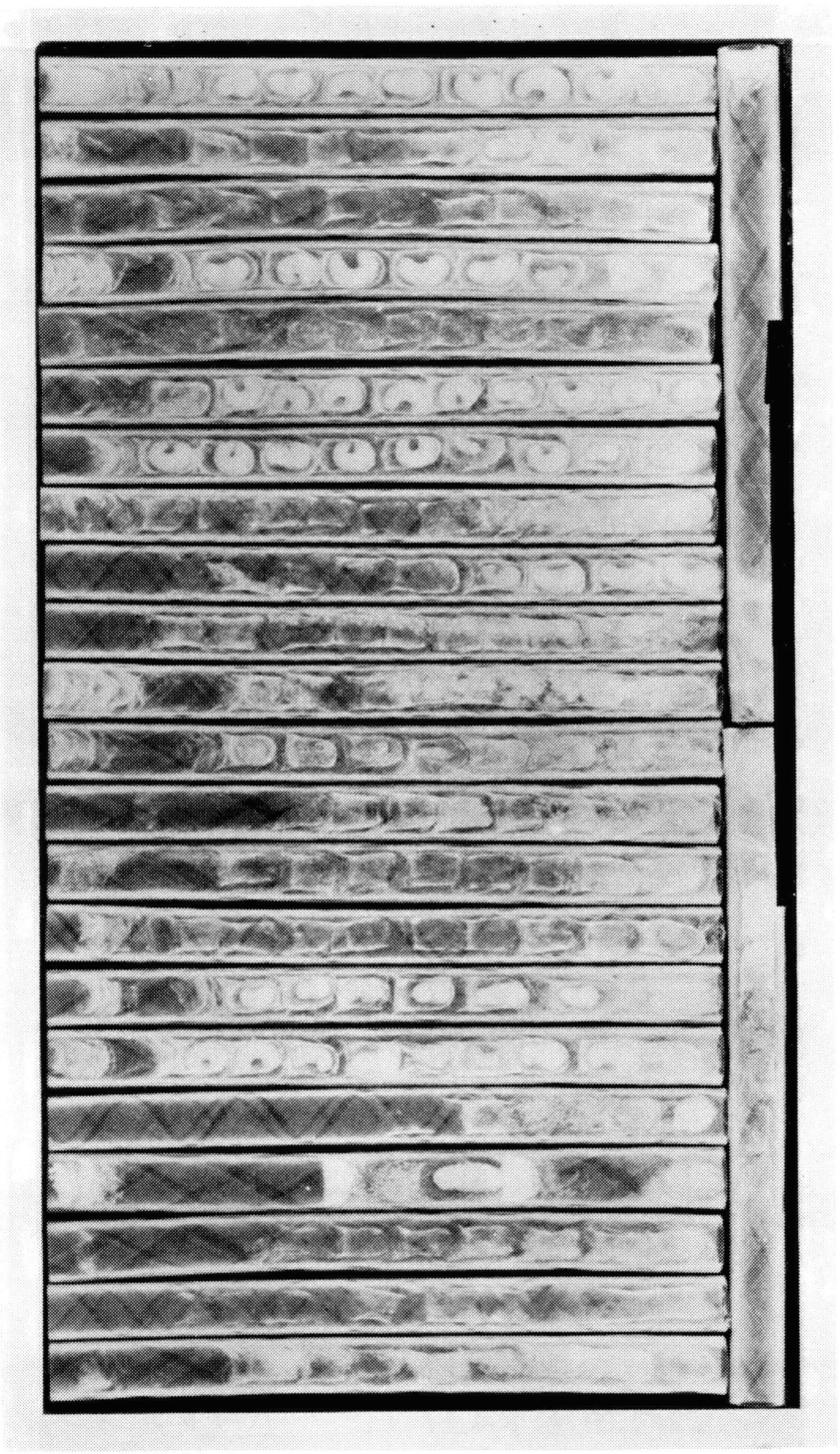

Figure 27. Week 37, Field C1, Carton B

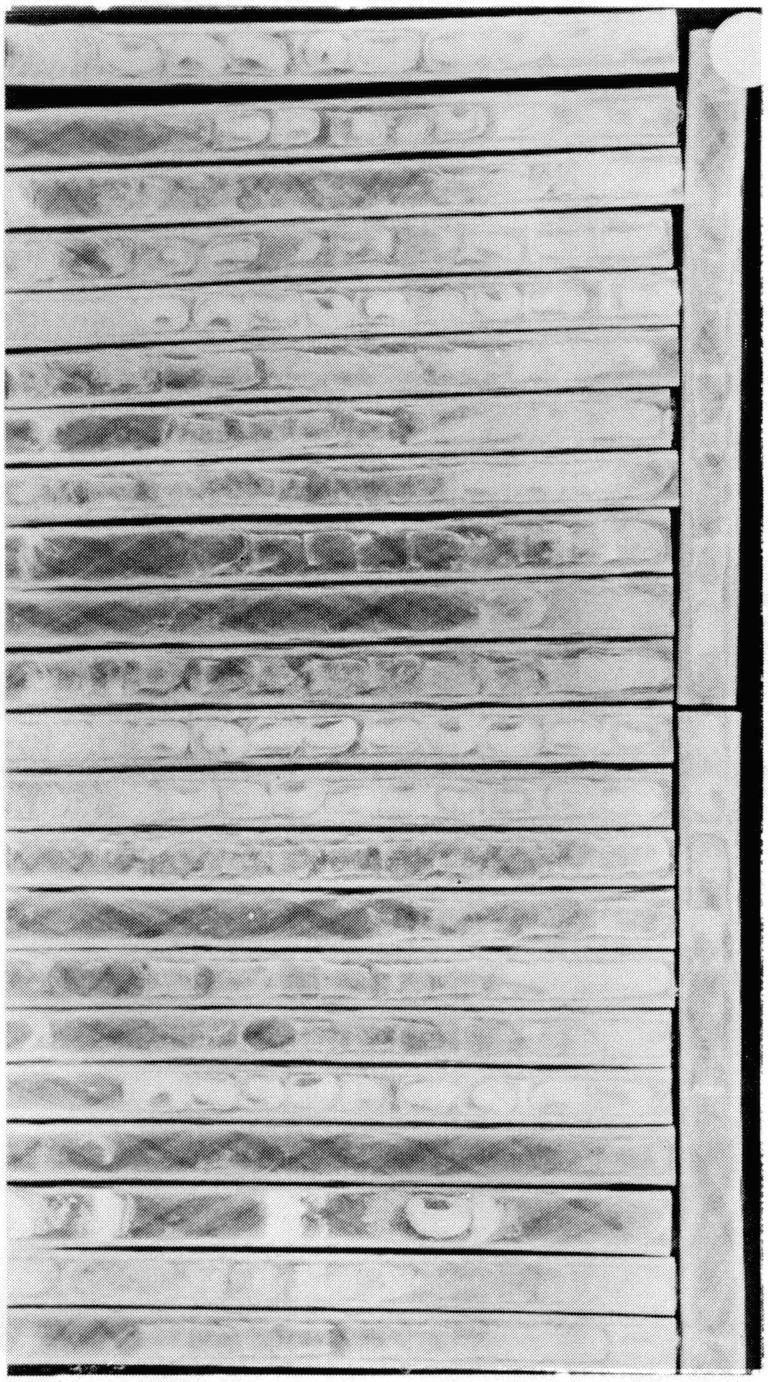

Figure 28. Week 44, Field C1, Carton A

VITA 2

Dale Leonard Maki

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF FIELD CELL-REMOVAL TIME ON THE OVER-WINTERING SURVIVAL OF THE ALFALFA LEAFCUTTING BEE, MEGACHILE ROTUNDATA (FABRICIUS)

Major Field: Entomology

Biographical:

Personal Data: Born in Ann Arbor, Michigan, May 12, 1951, the son of George A. and Joyce D. Maki. Married to Patricia Ann McPherson on June 9, 1979. Father of two sons, Jason D. and Joshua D. Maki.

Education: Graduated from Belleville High School, Belleville, Michigan in June, 1969; received Bachelor of Science degree in Entomology from Michigan State University, 1973; completed requirements for the Master of Science degree at Oklahoma State University in May, 1985.

Professional Experience: Hybrid bee program assistant, Dadant & Sons, Inc., Hamilton, Illinois, June, 1973 to July, 1974; Peace Corps Volunteer, Chile, South America, August, 1974 to November, 1976; Teaching Assistant, Department of Entomology, Oklahoma State University, spring semesters, 1981 and 1982; Agricultural Research Technician (Insects), USDA-ARS, Stillwater, Oklahoma, January, 1979 to present.

Professional Memberships:

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Kansas Entomological Society
Southwestern Entomological Society
International Agency of Apicultural Development Volunteers in Technical Assistance